TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

EDINBURGH.

VOL. XXIX.

EDINBURGH:
PUBLISHED BY ROBERT GRANT & SON, 107 PRINCES STREET,
AND WILLIAMS & NORGATE, 14 HENRIETTA STREET, COVENT GARDEN, LONDON.

MDCCCLXXX.

PRINTED BY NEILL AND COMPANY, EDINBURGH.

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TRANSACTIONS.

I.—*Chapters on the Mineralogy of Scotland. Chapter Fifth.—The Micas; with description of Haughtonite, a new Mineral Species.* By Professor HEDDLE.

(Read 3d February 1879.)

MUSCOVITE.

Muscovite is so easily recognised by its optical properties that the only cases which seemed to me to call for analysis were those which, from being possessed of characteristic colour, were of special interest.

Of these the most singular is a variety found rarely in the great vein of Ben Capval, Harris; it occurs in crystals of a peculiar green tint, the crystals are small and have somewhat of a pearly lustre.

On 1·2 grammes—

Silica,	·511		
From Alumina,	· 6		
	·517	=	43·083
Alumina,			32·858
Ferric Oxide,			·736
Ferrous Oxide,			2·764
Manganous Oxide,			·083
Lime,			1·073
Magnesia,			·333
Potash,			9·084
Soda,			·847
Water,			9·122
			99·983

Loses in bath 2·793 of the above water.

It would thus appear that the ferrous oxide is the source of the colour.

The iron of muscovite has hitherto been almost invariably set down as being in the ferric state:—it is very probable, however, that its condition had not been often determined.

The amount of water is here high; most analyses of micas would seem to have been executed on material dried at 212°.

Two other delicately-tinted micas may be suggested to future investigators for examination; namely, a brilliant-lustred yellow mica, from Struay Bridge in Ross-shire, and a somewhat rose-tinted variety, from Glen Skiag in the same county.

Muscovite is not so markedly typical of granites in Scotland as elsewhere, being largely replaced by the dark-coloured micas;—doubtless some dark grey muscovite may exist, but I have never myself found such, or any of a brown or black colour.

The finest specimens of muscovite in Scotland are found at the following localities:—

Large rosette crystallisations occur in a very quartzose vein to the west of Bigsetter Voe, in Mainland, Shetland; still larger at Loch Glass, in Ross-shire, at Glen Skiag in the same county, and at Struay Bridge in Inverness-shire. A crystal 15 inches in length was found in the very singular vein, if vein it should be called, in Glen Skiag. The windows of the smaller houses in Duffus are said to have been at one time "glazed" with sheets of muscovite.

I have determined the optic angles of the following micas:—

Axis in plane of longer diagonal.

Rich brown, great vein of Rubislaw,	67° 45′
Yellow green, great vein of Ben Capval,	72° 15′
Light brown, third vein east of Portsoy,	64° 30′
Pale rose, Glen Skiag,	71° 45′
Silvery, exfiltrative vein, Rubislaw,	69° 5′
Light brown, Loch Glass,	71° 40′

In taking the specific gravity of the Glen Skiag mica, it was found that after having been boiled in water—to expel air bubbles—and being suddenly cooled, its specific gravity was 2·832; but after lying for twenty-four hours in water, its specific gravity was only 2·782. Upon being suddenly cooled after boiling, the mica seems to contract beyond its normal condition; there being a difference of ·05.

A specimen of the Rubislaw mica, treated in the same way, gave after boiling and sudden cooling a specific gravity of 2·813; after lying in water for four hours, of 2·783. Here there would appear to be the same undue contraction, resulting from the sudden cooling, though not to the same extent.

The larger plates of mica contain imbedded substances which will be afterwards noticed.

Muscovite chiefly occurs in veins, either intrusive or exfiltrative; in these it invariably presents itself in larger crystals than those which are present in the general mass of the rock; and it would also appear to be present in these veins in a greater total relative amount than in the parent rock itself. This, should it be so, is not altogether difficult of explanation, if we are entitled to regard the rock as *the parent* of the vein.

To the granitic belts of metamorphic rocks, and the intrusive granitic dykes of all rocks, such a term of relationship could only be very indirectly applied; but to the exfiltrative veins of granitic rocks themselves, there is every reason to believe that the word fittingly applies.

Such veins, in the old terminology of the science, were called *contemporaneous,*—a word somewhat puzzling in its application, and misleading at the best.

A disquisition by Professor JAMESON on these "contemporaneous veins" forms the first of the publications of the Wernerian Society.

It would appear to have been JAMESON'S purpose to show the distinction between these veins and what we would now call *metallic lodes;* though it is not altogether clear that his description would not in some respect include injected veins therewith.

He thus defines them:—

> "1. *True veins* traverse different strata, and are confined to single beds or strata only in those cases where the strata are of uncommon thickness. Their direction is not tortuous, and they seldom give off many branches. The mass of the vein is generally distinctly separated from its walls: it is frequently disposed in beds or layers, and these are parallel with the walls of the vein. The beds of these veins are so arranged that the newer beds are contained in the older. They often contain fragments which lie promiscuously, and are either acute angular, blunt angular, or rounded. Lastly, the materials of true veins are more or less different from the rock which they traverse, and the same vein contains several formations.
>
> "2. *Contemporaneous veins.*—Their course is tortuous, and they give off numerous branches. The mass of the vein is generally intimately mixed with, and passes into that of its walls, and differs but little in its component parts from that of the rock which it traverses. They never contain more than one formation, and when they contain apparent fragments the structure of these is ever conformable to that of the contiguous rock. Lastly, they traverse but single beds and strata, and are observed to wedge out in every direction, and consequently have no outgoing above, below, or laterally, intimating that they have not been filled from above or below, but are as it were a secretion from the rock itself."

The above, so far as it goes, is an admirable description of exfiltrative veins, but it hardly sufficiently draws a line of demarcation between them and injected veins; while the illustrations which JAMESON supplies show unmistakably that he had confounded exfiltrative veins both with injected veins and with the granitic and other bands or belts of rocks.

Such bands in gneiss are instanced as illustrations, as are also the quartzose and micaceous bands of mica slate; and these are placed in the same category with the "veins of calcspar which traverse transition-limestone."

Perhaps nothing could better show the objectionable character of the term *contemporaneous* than JAMESON'S statement that "serpentine contains contemporaneous veins of asbest, talc, steatite, and lithomarge."

In JUKES' "Manual of Geology" the name is confined to their occurrence in intrusive rocks, but the above quotations from JAMESON will show that the word orginally had a much wider application. The authors of the most recent edition of this work propose to "retain the name for the purpose of expressing that the veins belong to the same intrusion as the masses which contain them."

While the very name of *vein* is objectionable, there is little hope of setting it aside, or, sooth to say, of getting a more fitting word from our own language; but it is the adjective to which strong exception must be taken, if contemporaneous is held to be at all synonymous with simultaneous. It is more than difficult to conceive of any one of the structures to which the term has been applied being paragenetic in time with the rock-masses in which it is imbedded.

Of such of these structures as occur in volcanic rocks, we read in JUKES' "Geology:"—

> "They seem in certain cases to have been produced from some movement of the whole mass during consolidation, whereby yet fluid portions were injected along cracks or between divisional planes of the mass.
>
> "In other instances, where they are found to merge into the surrounding rock along both their bounding surfaces, they rather suggest the idea of segregation and crystallisation of the mineral along particular lines."

The former of these modes of accounting for their formation is certainly adequate to explain the mode of filling up of crevasses,—especially volcanic rents,—in lava streams or other plastic igneous rocks; while the second may suffice for rectilinear, though hardly for branching or angularly tortuous veins: but it is evident that the above explanations are intended to be restricted to veins in igneous rocks; and as regards their occurrence in metamorphic rocks, where they are not only immensely more numerous, but very much more important as bearing upon the nature of metamorphism itself, no such modes of explanation can meet the facts of the case.

Putting out of consideration, meanwhile, the granitic bands or layers of hornblendic gneiss, and also the intrusive dykes which cut and ramify throughout them, we observe of these so-called contemporaneous veins, where they show themselves in their extraordinary development in the grey granite of Aberdeenshire, that they present three features which are unvarying:—

First,—That though their course may be in the main tortuous or curving, it, if followed sufficiently far, will suddenly become angular and zig-zag; as if, though the general solidity and cohesion of the rock mass was only such as to enable it to rend by tearing, it in certain of its parts was so rigid that it had been cracked or split.

Second,—The occurrence in the veins of fractured, and occasionally of apparently floating angular fragments of the rock, likewise points to an actual solidification of the rock previous to the disruption and envelopment of the fragments.

Third,—The gradual increase in the size of the crystals which fill these veins as they approach the centres thereof, the frequent capping of the quartz crystals (a recognised proof of intermittent growth), and the fact that any free crystalline summits which may be present invariably point to these centres, show that a sudden injection from without, and consequent more or less uniform and rapid cooling and solidification, could not be the manner in which the rents were filled. The relationship of the vein to the rock mass itself also negatives injection. There is no *line of separation* between the vein and the rock; the granular structure of the rock is, in narrow space it is true, but still *gradually* augmented in size; and this ampler crystalline structure of the vein seems to grow out of, to be rooted in the substance of the rock.

The change of structure takes place within the space of an inch, but within no part of that inch can the stroke of a hammer effect a separation.

The information conveyed by the hammer is indeed of a most instructive description.

Granular though the structure of granite is, its grains do not lie in confused arrangement. It may not be to the smallest extent *bedded* in the quarry, though it generally is; but granite has a perfect cleavage and cross cleavage, so determinate in their directions that the workmen speak of *the bedding* of even such quarries as present great faces of apparently perfectly continuous and unvarying rock.

These cleavages result from a general polarity in the crystals of felspar, which have their axes, and hence their cleavages, lying in the main in one direction. Thus the quarryman by blow and cross blow cuts the rough paving stone, so as to leave himself only the narrower faces to "dress to square."

But, inasmuch as the crystals of felspar which grow out of the rock to fill these exfiltrative veins do so at right angles to the sides of the vein, and as no one of the cleavages of felspar is at right angles to its main axis, the hammer blow cannot effect a separation throughout any part of the space wherein this rectangular riveting of the two structures is effected.

It would be far from easy to adduce any evidence which could more conclusively show that the present contents of these veins had *exuded* from the rock mass itself; and it need hardly be noticed in this connection that these veins never contain a single mineral substance which is not to be found in the rock mass itself; though, in the latter, many of these substances are of difficult recognition from their comparatively very small magnitude.

There is a fourth feature, moreover, which is not infrequent, namely, that the veins are cut by others. In one of the smaller openings of the granite quarry of Anguston this is admirably seen: here a darker shaded, finer grained, and narrower set of veins cuts others, which are wide, and which are paler in colour than the ordinary granular rock.

The numberless quarries which pockmark Aberdeenshire afford unusual facilities for studying its "grey granite;" such study, whenever entered upon, tends to the conclusion that the granite results from the metamorphism of the gneiss in which it is everywhere embosomed, and with which it is so intricately wrapped up.

In this district the metamorphism appears to have taken place under three different sets of circumstances.

In the first of these,—by what may be called a gradual incrementation of the granitic over the normal gneissic structure.

In the second,—by an abrupt and, as read by the eye alone, an inexplicably sudden transition of the latter into the former.

In the third,—by a general fading or softening away of the transmutible into the transmuted.

Throughout the whole of the gneiss of central Scotland, and more especially in these districts where the rock exhibits the clearest marks of alteration, it is pervaded by granitic bands, which, there is reason to believe, have not unfrequently been considered to be intrusive or injected veins.

That they are not so, but are merely the segregation of certain of the mineral constituents of the rock—like consorting with like—is evidenced by the following four facts.

These bands or layers of felspathic and quartzy matter invariably follow implicitly every flexure of the rock (developed and disclosed by the adjacent micaceous layers), never cutting across these or branching to the smallest extent. They do not maintain anything of a uniform width, but repeatedly diminish and expand, in accordance with the abruptness or looseness of the folds into which the rock is thrown. Though highly felspathic, and often markedly crystalline, they exhibit unmistakably in some portion of their bulk a laminated arrangement of particles, which becomes more and more distinctly pronounced as it passes into the ordinary structure of the rock. The blow of a hammer recognises no point at which the two structures are of facile separation; the transition of the one into the other being so gradual that no two persons would agree as to the point where each terminates,—and a handbreadth would not cover the debatable space.

The ingredient of mica, moreover, is markedly *deficient* in these so-called granitic bands.

I instance the north-east side of the hill of Scoltie, near Banchory, as a locality where such "veins" may be studied, specially in connection with the first of these changes; because about a couple of miles north of this, in the railway cutting west of Banchory, this gneiss is *becoming granitic* through a regular increase in the number and in the volume of these granitic bands. Here also there is a marked change in the nature of the bands themselves; they no longer exhibit the laminated structure, but are throughout their whole extent true granite of a uniform fine grain; and although the hammer can still discover no line of separation, yet a finger's breadth will here cover the space through which the structures pass from one to the other.*

In following the line of railway to its next cutting, nearer to the Hill of Fare, the granitic bands will be seen progressively augumenting in width, and the gneissose bands dwindling to evanescence.

For such as I have now described, and also for the more rectilinear modification thereof which occurs in hornblendic gneiss, I would propose the term *bands of metamorphic segregation.*

The second mode of change is well seen in the quarries at Tillyfourie.

The gneiss, which here presents bold features,—being highly contorted, broadly banded, the bands showing an abrupt contrast in their coloration,—passes into granite with an abruptness which is quite startling.

There is not a trace of interstitial skin or intermediate mineral body; most assuredly there has been no intrusion of the granite here,—the one rock ceases to be, and the other commences along *no line* which can be seen or felt; there is no portion of space in which the one can be said to be in contact with the other; the continuity is everywhere unbroken, the material continuous, the eye alone appreciating a marked change of colour and of structure, for the openings between the foliæ of the gneiss suddenly cease to exist, but this they do not along a rectilinear but a wavering course. A hammer blow rends the rock in any direction, the line of fracture crossing the zone of changed structure at all angles, and the straight course of the fracture being uninfluenced in the so doing. The only modification of this structure is, that occasionally the dark mica of the granite has its plates disposed in arrangement somewhat parallel to the course of the transition, within the space of an inch or two from the unchanged rock.

The third mode of change is seen in the several quarries of the Stony Hill of Nigg; here a fine-grained, plicated, and darkly-striped gneiss may be traced, with gradually fading layers, into a uniformly granular, dark grey granite. In many of the Aberdeenshire quarries, moreover, semiangular fragments, large and small, of the darker and more micaceous layers of the gneiss, are found imbedded, rounded in their outlines into kidney-form ("*neres*"), and darkening the granite in their immediate vicinity by a quantity of the black-mica (Haughtonite) which these "neres" contain. It would

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* While confounding these bands with "contemporaneous veins," JAMESON saw clearly their marked features. He writes—"These veins do not present the slaty structure which is one of the discriminating characters of gneiss when it occurs in strata; hence contemporaneous veins, filled with common granular, or what may be called granitic gneiss, have been confounded with true granite." Thereby meaning common or *eruptive* granite.

appear that the plates of the black mica have been loosened from the surfaces of the neres, and have become impacted in the adjacent substance of the granite, but have remained unresolved into smaller crystals; the metamorphism being arrested, or incomplete at these points.

Of the metamorphism of this granite, however effected, the exfiltrative veins would appear to have been one of the last stages.

How often the grey granite may have been depressed to the zone of metamorphism we cannot say, any more than we can how often the aquo-thermal agencies had to operate upon it; but, during some one of the subsidations, it is rational to conceive of its having been rent by pressure, and that subsequently—perchance forthwith—the rents were filled up, not by any sudden injection from their open terminations, but *by a process of transfusion from all points of the surface of the rent,* a transfusion of the plastic or soluble matter of the rock itself,—endosmose and exosmose exercising their resistless force. The resulting plug is thus—to use JAMESON'S words—"*a secretion from the rock itself.*"

DAUBREE'S experiments have shown that in the presence of water a temperature of 400° C. sufficed for the alteration of silicates,—crystallisation of silica and of felspar,—or for the actual formation of the latter and of mica, through the action of alkaline silicates on argillaceous rocks. Considering the changes which would result from aquo-thermal action in the light of these experiments, and knowing that the repeated action of heated water upon the more highly siliceous rocks invariably results in the greater adhesion of water for the alkalies,—progressively abstracting them, to leave more and more highly-aluminous silicates,—it is not difficult to understand how the amount of mica in these exfiltrative or exudation veins should be in excess of its proportion in the parent rock. For, if the general mass of that rock be held in solution through aquo-thermal action,—or if not in actual solution, in a condition favourable to chemical change, the rock upon solidification must yield a mass which is less alkaline as a whole; and as in the case of granite it is the orthoclase which is the alkali-bearing mineral, it is this which would suffer loss. The resolidifying material, after the watery abstraction of some of the alkali, could no longer attain to the production of so much felspar,—some of which would be degraded, so to speak, into an increase of the amount of mica.*

Now there is what may be called a physical-outcome of this change.

In virtue of this abstraction of alkali from orthoclase, and consequent increase of free silica and formation of mica, there results the production of a less alterable, that is, a more enduring material; and if it be the case that granite-veins contain more mica than does the rock which they intersect, these veins must necessarily be more enduring than the granite itself.

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* The alkali-charged waters are, however, potent, even at low temperatures, to change clay slates and argillaceous gneiss into granite, and so to *extend the sphere of the metamorphism.*

The protrusion of granite veins above the ordinary level of the rock—quite a familiar fact—may be partly due to their less minutely granular, that is, less uniformly porous and loose-grained structure; but the almost invariable protrusion of the plates of mica, even above the quartz, in granite veins, vouches unmistakably for the greater endurance which that mica must impart.

The not unfrequent occurrence of loose blocks of large-grained granite in straight line across a heath-covered or grass-clad surface points also to a former vein, which had longer resisted the denudation due to atmospheric decay than had the inclosing rock.

This is a subject which, as a whole, has certainly not engaged the amount of attention which it merits. Probably the following structures have to be discriminated, and have been more or less confounded with one another :—

Ingredients same as those of the Rock-Mass itself.

1. *Plugging pre-existent Rents.*

Contemporaneous plugs of rents in igneous rocks
intersect rock in curving and angular manner; structure *smaller* than that of the rock-mass; both branching and intersecting; formed by sudden injection.

Veins of exfiltration
intersect rock in curving and angular manner; structure *larger* than that of containing rock; both branching and mutually intersecting; formed by a single continuous process.

Metalliferous veins
frequently intersect more than one rock-mass; generally rectilinear but angular; structure larger than that of containing rock; branch, and cut rocks of different natures; formed by intermittent actions, diverse in their natures, and markedly so in their products.

2. *Not filling pre-existent Rents.*

Bands of dominant crystalline action
accordant with the floor or surface of igneous flow; structure larger than that of containing rock; neither branching nor intersecting; frequently spherulo-radiate in structure.

Bands of metamorphic seggregation
accordant with flexures of rock strata; structure larger than that of containing rock; neither branching nor intersecting; of ever-varying thickness in plicated rocks.

Veins of seggregation
angular, and intersecting rock strata; structure larger or smaller than containing rock; both branching and intersecting; generally accuminated at their terminations.

Ingredients not the same as those of the Rock-Mass

intersect more strata than one, in all directions and ways; frequently branch and intersect each other.

a. Granitic dykes, structure *larger* than including rock; frequently fill faults.

b. Trap dykes, structure *smaller* than including rock; fill rents.

MARGARODITE.

From Gneissose Rocks.

1. From a stratum of kaolin which occurs at Mouwick, Lambhoga, Fetlar, Shetland.

Kaolin is not found in many localities in Shetland, but when found it occurs in considerable quantities. Mouwick and Grunies' Geo in Fetlar, the burn of Tractagill, and the trough which runs north from Weesdale Hill are the chief localities. It has been in these islands used as a Fuller's-earth, and for white-washing houses. In all of the above localities it has a glistening appearance, which seems in all to be due to its containing, like that found at Mouwick, a quantity of minute scales of margarodite. Of this the kaolin of Mouwick yields to elutriative processes about one-fifth part. This margarodite has a faint yellow colour, a pearly lustre, and is very unctuous to the touch. It may by continued friction be reduced to very minute scales, but not to an absolutely impalpable powder like talc; this is a physical mode of discrimination between these minerals.

1·302 grammes of this margarodite yielded—

Silica,	·655		
From Alumina,	·006		
	·661	=	50·768
Alumina,			31·711
Ferric Oxide,			1·315
Manganous Oxide,			·23
Lime,			·946
Magnesia,			·786
Potash,			5·11
Soda,			·53
Water,			7·969
			99·347

It absorbs ·89 per cent. of water.

The "kaolin" also contains a quantity of grains of angular quartz.

2. From Vanleep, Hillswick, Shetland. Occurs, associated with reddish coloured kyanite, in the quartz veins of a very micaceous gneiss; it is imbedded along with ripidolite (?) in crystals, or crystalline plates, among the interlacing crystals of the kyanite

Colour almost white, sometimes very pale greenish: lustre very high pearly, almost equal to talc.

Crystalline system the orthorhombic, form like muscovite,—optic axis in plane of longer diagonal of the crystal,—optic angle 67° 5′.

A twin crystal, with two intersecting systems of rings, is in the author's possession.

A small quantity was treated with sulphuric acid, and a similar quantity with hydrochloric.

The sulphuric acid seemed rapidly to decompose the mineral, the silica rising in light clouds when stirred.

The hydrochloric acid was rapidly turned yellow; but, even after repeated evaporation with fresh quantities of acid, perfect decomposition could not be effected; the mineral remaining as a heavy white powder.

Specific gravity 2·825; H. 2·25.

22·87 grains yielded—

Silica,	45·426
Alumina,	29·652
Ferric Oxide,	8·328
Manganous Oxide,	·022
Lime,	·788
Magnesia,	1·702
Potash,	6·94
Soda,	2·267
Water,	5·293
	100·418

Insoluble silica, 5·68 per cent.; possible impurity, kyanite.

Was examined under the supposition that it was Damourite.

3. It is very probable that most of what has been regarded as talc-slate in the Highlands of Scotland will in almost all cases prove to be margarodite-slate, or other hydrated mica-slates.

Hibbert mentions many such slates as occurring in the Shetlands. One, which he specially draws attention to, he says is to be found a little to the north of Vanleep in Hillswickness. He describes the pellicular form, brilliant pearly lustre, and remarkable unctuosity of the mineral to which the schistose character of the rock is due. He also notes the want of elasticity in the "pellicles." These pellicles were analysed specially to ascertain if so-called talc-slates were of the nature assigned to them in the name.

The pellicles were picked from the more quartzy bands of the rock, as there they seemed always to be of increased size.

They had little or no elasticity, but this I find to be not unusual with margarodite.

18·5 grains yielded—

Silica,	45·421
Alumina,	30·3
Ferric Oxide,	6·874
Manganous Oxide,	·816
Lime,	·6
Magnesia,	2·6
Potash,	6·088
Soda,	2·01
Fluorine,	1·06
Water,	5·011
	100·78

4. From Botriphnie, Banffshire. Is the matrix of kyanite, in a specimen ticketed by Abraham Clark of Portsoy.

Lustre very splendent, colour white; appeared to be in six-sided plates.

On 11·011 grains—

Silica,	45·103
Alumina,	29·9
Ferric Oxide,	7·87
Manganous Oxide,	·031
Lime,	·62
Magnesia,	.723
Potash,	7·836
Soda,	2·556
Water,	5·512
Fluorine,	tr.
	100·151

Possible impurity, kyanite.

Was thought Damourite.

From Granular Limestone.

5. Occurs in the limestone quarries in the balloch between Glenbucket and Glen Nochty, Aberdeenshire.

Is associated with pyrite, pyrrhotite, rutile, and actynolite. Occurs in rosette groups of crystals; colour white; lustre silvery; very much resembles talc,—for which it was taken, until the hardness was tested.

1·141 grammes yielded—

Silica,	·505	
From Alumina,	·022	
	·527 =	46·18
Alumina,		31·83
Ferric Oxide,		4·1
Lime,		1·66
Magnesia,		1·23
Potash,		8·81
Soda,		1·31
Water,		5·714
		100·834

Absorbs ·2 per cent. of water; possible impurity unknown.

Loses its water at the temperature afforded by a Bunsen burner,—talc requires a blast furnace for its dehydration.

Both the stratum of limestone which first shows itself on the coast of the Moray Firth, at Sandend, in Banffshire, and which passes up among the flags of the Vale of Deskford, Glen Rinnes and Strath Avon, cuts the high ground at Inchrory and Loch Bulg, and possibly reaches the low country through Glen Tilt,—and that which first appears at Boyne-mouth, coursing to the east of the quartzite and causing the ballochs of Glenbucket, Glen Nochty, Strath Earnan, and Tornahaish, afford this brilliant margarodite. Throughout it simulates talc, and has as its unfailing associate pyrrhotite,—less frequently rutile, and sahlite or actynolite.

MARGARODITE.

	$\ddot{\mathrm{Si}}$.	$\dddot{\mathrm{Al}}_2$.	$\dddot{\mathrm{Fe}}_2$.	$\dot{\mathrm{Mn}}$.	$\dot{\mathrm{Ca}}$.	$\dot{\mathrm{Mg}}$.	$\dot{\mathrm{K}}_2$.	$\dot{\mathrm{Na}}_2$.	F.	$\dot{\mathrm{H}}_2$.	Total.
Lambhoga, with Kaolin . .	50·77	31·71	1·32	·23	·95	·79	5·11	·53	...	7·97	99·35
Vanleep, Shetland, with Kyanite,	45·43	29·65	8·33	·02	·79	1·7	6·94	2·27	...	5·29	100·42
Vanleep, Shetland, with Quartz, .	45·42	30·30	6·87	·82	·6	2·6	6·09	2·01	1·06	5·01	100·78
Botriphnie, Banffshire, . .	45·1	29·9	7·87	·03	·62	·72	7·84	2·56	tr.	5·51	100·15
Glenbucket, Aberdeenshire, . .	46·18	31·83	4·1	...	1·66	1·23	8·81	1·31	...	5·71	100·83

Black Micas.

Most geological works enumerate among the constituents of certain granites and gneisses,—"a dark magnesian mica,"—"a brownish-black magnesian mica,"—or "a greenish-black magnesian mica,"—as the case may be; but do not specify what the mica is.

Mineralogical works, again, present us with three "dark magnesian-micas,"—phlogopite, Biotite, lepidomelane. Mineralogical works, one and all, are unsatisfactory as regards the amount of information they convey as to the habitudes of minerals,—their lithological habitats.

Phlogopite there is some precision as to; it is said, to be "especially characteristic of serpentines, and crystalline limestone, or dolomite." Biotite, or the micas placed under that heading, would, on the authority of said works, appear to occur almost everywhere. Lepidomelane is given as occurring in syenite, granite, and quartzite.

Dr HAUGHTON has imported some precision into this question, as regards the dark granitic-mica, so far as Ireland is concerned; but the conclusion he arrived at does not, singularly enough, apply to Scotland. And again, while I have not yet met with a single specimen of phlogopite in Scotland, I find that it must, as regards this country, be said of Biotite, and not of phlogopite, that it is "specially characteristic of crystalline limestones," seeing that, with the exception of margarodite, and it only rarely, I find no other mica in that rock.

The dark magnesian mica, which, in Scotland, is specially characteristic of granites, will be shown to be a new, or at least an unrecognised species.

PHLOGOPITE.

I have not yet, by analysis, been able to show that phlogopite occurs in Scotland.

The light-brown Biotite from the limestone of Shinness—the analysis of which is given below—is in appearance very similar to some foreign phlogopites; but upon this proving to be Biotite, all resembling it which were not analysed were considered to be Biotite also.

In specimens of granular limestone from the Vosges, there is a mica named phlogopite by Professor KING, which is so similar to the limestone-mica of Glen Elg, that it is possible that the latter may prove to be this most highly magnesian species. It however occurs in so small an amount in the lime, that a special visit to the locality could alone ensure a sufficiency for analysis.

BIOTITE.

From Granular Limestone.

1. The limestone, which is the near associate of the serpentine of Polmally, in Glen Urquhart, appears in greatest amount, at a height of 700 feet, in the hill above Milltown. The somewhat schistose gneiss, which here carries the lime, is thrown into endless and most intricate folds, which are laid bare in the numerous limestone quarries which are sprinkled over the hill-face ; several of these, and markedly the most northerly, show a peculiar granite vein or belt, which generally cuts but occasionally follows the bedding of the lime. This vein consists of little quartz, and much of a bluish white, opaque, fatty-lustered andesine, carrying imbedded crystalline plates of Biotite.

Any associated minerals belong to the lime.

The Biotite is in plates of an inch or more in size, of a dark pinchbeck brown colour, a shining lustre, sometimes somewhat greasy.

Its specific gravity is 2·867.

1·3 grammes yielded—

Silica,	·476	
From Alumina,	·037	
	·513	= 38·692
Alumina,		17·661
Ferric Oxide,		·255
Ferrous Oxide,		12·952
Lime,		1·163
Magnesia,		17·538
Potash,		8·917
Soda,		·126
Fluorine,		·522
Water,		2·137
		99·963

Insoluble silica, 1·391 per cent. Possible impurity unknown.

A similar vein in the large quarry carries, in addition to the above minerals, crystals of delicate green apatite, crystals of brown sphene, of grammatite, and of dark-green Allanite.

2. Found in a quarry on the north side of the road about a mile east of Laggan Inn, Inverness-shire.

The lime, which has a north-north-east and south-south-west trend, contains little else than a fine-grained chlorite, and this is immediately associated with the Biotite, which is usually imbedded in the former in thin plates of an inch or two in size. Its colour is bronzy.

On 1·2 grammes—

Silica,	·458	
From Alumina,	·016	
	·474 =	39·5
Alumina,		15·036
Ferric Oxide,		·244
Ferrous Oxide,		10·229
Manganous Oxide,		·75
Lime,		1·4
Magnesia,		18·461
Potash,		9·366
Soda,		·618
Fluorine,		·73
Water,		3·214
		99·558

Insoluble silica, 2·531 per cent. Possible impurity, chlorite.

3. From the limestone at Shinness, Sutherland. Biotite, similar in appearance to the last, is to be seen rarely at this locality. More frequently it occurs in dark-brown almost black plates which sheathe sahlite, and still more frequently in the form which was chosen for the analysis,—namely, in small crystals superimposed on one another, so as to present a foliaceous structure.

It was in immediate association with sahlite and brown sphene.

The crystals were of a light greyish-brown colour, and a greasy lustre ; they were suspected to be phlogopite.

1·3 grammes yielded—

Silica,	·513	
From Alumina,	·004	
	·517 =	39·769
Alumina,		16·676
Ferric Oxide,		·653
Ferrous Oxide,		6·73
Manganous Oxide,		·615
Lime,		2·196
Magnesia,		20·923
Potash,		6·5
Soda,		·476
Water,		5·398
		99·936

Insoluble silica, 1·74 per cent. Possible impurity, sahlite or sphene.

4. From granular limestone at Glen Beg, Glen Elg.

At about one-fourth of a mile to the north-east of the hamlet of Balvraid, the limestone contains Biotite (in association with the hydrated labradorite—noticed in Chap. II. of this series), necronite, and balvraidite.

The mineral is generally immediately in association with the balvraidite.

Its colour is rich chocolate brown, its lustre brilliant.

1·28 grammes yielded—

Silica,	39·46
Alumina,	16·45
Ferric Oxide,	·39
Ferrous Oxide,	10·
Manganous Oxide,	·53
Lime,	1·59
Magnesia,	19·
Potash,	8·22
Soda,	·26
Fluorine,	·32
Water,	3·34
	99·56

Possible impurity, balvraidite.

From Hornblendic and Serpentinous Rocks.

5. Hornblendic gneiss, highly contorted and fractured, occurs in the peninsula of Hillswick, in Shetland.

At the point called the banks (*i.e.*, shores) of Nudista, a bed—simulating a vein of precious serpentine—protrudes, just north of the spot where these "banks" rise into rocky cliffs.

This bed is in contact on the south with one of matted anthophyllite; while it carries, partly in its centre and partly on the side opposite to the anthophyllite, another consisting of actynolite with a matrix of snow-white talc; this latter, in passing shorewards, loses the actynolite, and gradually merges into a soft talc-chlorite, as it reaches and passes beneath high-water mark.

Just about this point a considerable portion of the bed—here almost pulpy from absorbed water—consists of Biotite.

It is in a very loose and incoherent state, much resembling a friable talc.

Its colour is bronzy brown; it is translucent in thin fragments.

The scales fall asunder in water, so that the specific gravity could not be determined.

1·657 grammes gave—

Silica,	·634		
From Alumina,	·026		
	·660	=	39·803
Alumina,			14·185
Ferric Oxide,			2·594
Ferrous Oxide,	11·373,	11·748,	11·578
Manganous Oxide,			·24
Lime,			·097
Magnesia,			18·32
Potash,			8·43
Soda,			2·11
Fluorine,			·56
Water,			2·52
			100·437

7·905 per cent. of the silica were insoluble; possible impurity unknown. The larger than normal quantity of soda was, doubtless, due to marine submergence. In the larger quantity of ferric oxide which replaces alumina this Biotite differs from the others.

From Edenitic Rock.

6. At a turn of the road a little south-east of the Free Church of Milltown, Glen Urquhart, the serpentine appears at the surface, and here there is a small quantity of a very peculiar rock.

This is composed of large pale-green crystals of edenite, of the form of actynolite; these are bedded in a mass of plicated crystals of what has more resemblance to talc than to Biotite; their usual colours being a very pale green, little removed from white, and they are devoid of elasticity. As accessories, there occur thick veins of hydrous-anthophyllite, thinner ones of fibrous Wollastonite, garnet with imbedded zircons, and crystalline granules of a new mineral resembling chondrodite in appearance. This talc-like Biotite is unusually soft, softer indeed than the nail; its specific gravity is 2·781: occasionally it passes into flat and elastic plates of a rich brown colour, and high lustre.

The pale-coloured yielded on 1·3 grammes—

Silica,	·51		
From Alumina,	·005		
	·524	=	40·307
Alumina,			12·582
Ferric Oxide,			1·809
Ferrous Oxide,			3·335
Manganous Oxide,			·384
Lime,			7·581
Magnesia,			21·
Potash,			6·561
Soda,			·953
Water,			5·738
			100·25

Loss in bath ·454 per cent.

The amount of iron only was determined in the dark brown plates; these contained of ferric oxide 4·913, and of ferrous oxide 19·802 per cent., this large amount replacing lime and magnesia.

The large amount of lime in the pale variety is singular, taken in connection with the small amount of that earth contained in the Biotite found in limestone from a near-adjacent quarry. (See analysis No. 1.)

Biotite.

	S.G.	$\ddot{\mathrm{Si}}$.	Al_2.	$\dddot{\mathrm{Fe}}_2$.	$\dot{\mathrm{Fe}}$.	$\dot{\mathrm{Mn}}$.	$\dot{\mathrm{Ca}}$	$\dot{\mathrm{Mg}}$.	$\dot{\mathrm{K}}_2$.	$\dot{\mathrm{Na}}_2$.	$\dot{\mathrm{F}}$.	$\dot{\mathrm{H}}_2$.	Total.
Glen Urquhart, .	2·867	38·69	17·66	·25	12·95	...	1·16	17·54	8·92	·13	·52	2·14	99·96
Laggan, . .	...	39·5	15·04	·24	10·23	·75	1·4	18·46	9·37	·62	·73	3·21	99·55
Shinness, . .	...	39·77	16·68	·65	6·73	·62	2·2	20·92	6·5	·48	...	5·4	99·95
Glen Beg, . .	2·85	39·46	16·45	·39	10·	·53	1·59	19·	8·22	·26	·32	3·34	99·56
Hillswick, . .	...	39·8	14·19	2·59	11·58	·24	·1	18·32	8·43	2·11	·56	2·52	100·44
Milltown, Urquhart	2·781	40·31	12·58	1·81	3·35	·38	7·58	21·	6·56	·95	...	5·74	100·25

The latest published analyses of Biotite show that the iron is almost totally in the state of protoxide, and the above analyses put the matter beyond doubt.

The above Biotites were optically uniaxial, or biaxial to a very small extent—1° to 2°.

LEPIDOMELANE.

From Gneiss.

1. This mica—which Haughton has the credit of first introducing as British, if not of firmly establishing as a species—I have only found in Scotland at two localities. The first is near the north shore of Loch Shin, in Sutherland.

Not a little of the gneiss of central Sutherland is, in this neighbourhood, hornblendic. A bed of hornblendic rock occurs immediately over the limestone of Shinness, like it, with a northerly dip; to the north, and superior to this, again, a hornblendic gneiss stretches west and east for several miles.

The country is for the most part covered, but the rock has been exposed here and again in the drain cuttings made in connection with the great improvements at present being undertaken by His Grace the Duke of Sutherland.

Masses of rock, raised on the farm of Achadhaphriz, contained, imbedded in a felspathic and hornblendic base, crystals of sphene, very rarely of rutile, more commonly of apatite, and plates of from two to three inches in length of lepidomelane.

Colour yellowish brown to chocolate brown. Easily cleavable, but only in small pieces, being brittle; slightly biaxial; of a muddy yellow-brown by transmitted light.

Reduced to powder with comparative ease. Specific gravity, average of three pieces, 2·971.

On 1·3 grammes—

Silica,	·51		
From Alumina,	·015		
	·525	=	40·384
Alumina,			12·11
Ferric Oxide,			14·523
Ferrous Oxide,			3·03
Manganous Oxide,			3·146
Lime,			1·033
Magnesia,			13·
Potash,			7·128
Soda,			1·801
Water,			3·567
			99·722

Insoluble silica, 2·856 per cent.; possible impurity unknown.

The "glass" formed by the fusion of the mineral with Fresenius flux is of a very dark, almost black, colour.

From Exfiltration Veins in Granite.

2. Is one of the numerous minerals which accompany the Amazonstone in the vein in the "syenetic" granite, a boulder of which was found on Ben Bhreck, Tongue, as described in Chap. II. The lepidomelane was found in considerable quantity, in plates of an inch or two in size.

The appearance was very similar to the last. The colour was of a deep rich brown; it cleaves into somewhat larger foliæ than does the mineral from Achadhaphriz, these foliæ are almost opaque, slightly biaxial, and crush with ease. Specific gravity, 2·965.

1·3 grammes yielded—

Silica,	·511	
From Alumina,	·01	
	·521	= 40·076
Alumina,		12·408
Ferric Oxide,		13·474
Ferrous Oxide,		2·668
Manganous Oxide,		·615
Lime,		1·076
Magnesia,		14·661
Potash,		7·57
Soda,		2·153
Water,		5·293
		99·994

Loss in bath *none;* insoluble silica, 2·879 per cent. The "glass" is of the same pitchy blackness as that from the last locality.

Lepidomelane.

	S. G.	$\ddot{Si}$.	$\dddot{Al}_2$.	$\dddot{Fe}_2$.	$\dot{Fe}$.	$\dot{Mn}$.	$\dot{Ca}$.	$\dot{Mg}$.	$\dot{K}_2$.	$\dot{Na}_2$.	$\dot{H}_2$.	Total.
Achadhaphriz,	2·971	40·38	12·11	14·53	3·03	3·15	1·03	13·	7·13	1·8	3·57	99·72
Tongue,	2·965	40·08	12·41	13·47	2·67	·62	1·08	14·66	7·57	2·15	5·29	99·99

HAUGHTONITE.

From Dykes in Hornblendic Gneiss.

Lepidomelane—the ordinary black mica of the granites of Ireland—has been shown to be extremely rare in Scotland. There is another black, indeed much blacker mica, which is extremely common; this, however, is a perfectly different, in fact an unrecognised, if not an altogether new mineral.

I give the occurrence, description, and analyses first, and consider the question of specific-individuality later.

Two huge vertical granitic dykes cut the north-eastern foot of the great hill of Roneval in Harris; the most southerly of these runs from Loch Finsbay through the hill, striking towards the west shore; the other is seen half-way between this and Scuir Ruidh.

The white orthoclase of these veins is plentifully studded with crystalline masses of magnetite, and intersected by large plates of a dark brown-black mica, which are disposed more or less parallel to the sides of the vein, so as to exhibit only their edges on its glaciated section.

These edges are frequently eight to ten inches in length; some, measured by my confrere Mr DUDGEON and myself, were fifteen and sixteen. This mica splits readily into plates of considerable size, being tough, and not brittle like those of lepidomelane.

The plates transmit light of a dark brown-black colour, and are slightly biaxial. The mineral is powdered with extreme difficulty; the powder is black, with a slight shade of green.

The specific gravity is 3 · 03.

1 · 34 grammes gave—

Silica,	·486		
From Alumina,	·012		
	·498	=	37·164
Alumina,			15·006
Ferric Oxide,			7·689
Ferrous Oxide,			17·353
Manganous Oxide,			1·044
Lime,			1·128
Magnesia,			8·88
Potash,			8·18
Soda,			1·605
Water,			2·121
			100·16

The specimen seemed absolutely pure. The glass was of a light olive brown colour over the Bunsen; of a light blue after having been subjected to the heat of the blast furnace.

The state of the oxidation of the iron and its quantity were twice determined,—on both occasions by the action of calcium fluoride* and sulphuric acid,—a stream of carbonic acid being passed, during the whole process, through the apparatus.

On the first occasion ·1178 grammes yielded of ferrous oxide, 17 · 26 per cent.; on the second ·172 grammes yielded of ferrous oxide, 17 · 443 per cent.

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* My assistant, Mr DALZIEL, finds it advisable to use a mixture of potassium fluoride and calcium fluoride—the former being in excess. Less calcium sulphate is thus formed, and the platinum crucible is more speedily emptied of its contents.

In the ascertaining the percentage of water, it was found that the heat of the Bunsen produced no change of colour or of molecular state ; the heat of the blast, however, caused some agglutination.

1·499 grammes lost ·022 in water-bath ; over the Bunsen for two hours, lost ·0238 ; over the blast for a quarter of an hour, ·0318. The water is, therefore, retained with extreme tenacity.

2. From the great vein of Ben Capval.

Though this vein and those parallel to it, which cut the strata on the south shore of Harris between the Toehead promontory and Huishinish House, afford this mica, it occurs in these north and south veins in such very small quantities as to constitute a marked point of distinction between them and the radiating veins which intersect Roneval and the adjacent country.

Towards its northern extremity, the Capval vein afforded a sufficiency for analysis. The crystals here are of only an inch or two in size, elongated and diverging, jet black, rarely slightly rusty. They are biaxial to a small extent.

Their specific gravity is 3·071.

25 grains yielded—

Silica,	36·806
Alumina,	15·22
Ferric Oxide,	7·611
Ferrous Oxide,	17·353
Manganous Oxide,	·96
Lime,	1·54
Magnesia,	8·784
Potash,	8·31
Soda,	1·342
Water,	2·47
	100·396

Possible impurity unknown.

3. From Loch Roag, Lewis.

The road which passes along the north shore of Loch Roag skirts a small fresh-water lake called Loch-na-Muilne.

Granitic veins cut the gneiss on its northern banks, and in these and in similar veins in the cliffs, and in the highest knoll which is to be seen to the north-west, the mineral is to be found in plates of an inch or two in size. I is associated with pinkish orthoclase, pale blue oligoclase, fatty quartz, and occasionally hornblende. Its colour is dark brown to black.

1 · 3 grammes yielded—

Silica,	· 468	
From Alumina,	· 006	
	· 474 =	36 · 461
Alumina,		17 · 253
Ferric Oxide,		4 · 18
Ferrous Oxide,		15 · 325
Manganous Oxide,		· 538
Lime,		· 689
Magnesia,		12 · 23
Potash,		9 · 204
Soda,		· 657
Water,		3 · 385
		99 · 922

Loss in bath, · 325.

4. From Foinaven in Sutherland. The mineral occurs in bundles of interlocking plates, imbedded in great veins, at a height of 750 feet, on the west slope of the hill. The associates are large crystals of orthoclase, and oligoclase. The Haughtonite is here jet black in colour, and of an extremely brilliant lustre.

It seemed to be in hexagonal crystals.

Its specific gravity is 3 · 032.

1 · 2 grammes yielded—

Silica,	· 428	
From Alumina,	· 013	
	· 441 =	36 · 75
Alumina,		17 · 858
Ferric Oxide,		2 · 781
Ferrous Oxide,		15 · 175
Manganous Oxide,		· 416
Lime,		· 933
Magnesia,		11 · 166
Potash,		9 · 437
Soda,		1 · 247
Water,		4 · 232
		99 · 995

Loses · 967 per cent. of water in the bath. It is reduced to powder with extreme difficulty.

5. From Rispond, Sutherlandshire. The mass of graphic granite which occurs in the gneiss at the north side of Rispond harbour has been described in Chap. II.

The other associates of the Haughtonite are here oligoclase and magnetite.

The crystalline plates are here generally of only an inch or so in size; occasionally, however, they are much larger. They are of a deep black colour. All other characters and reactions agree with those of the Roneval mineral.

The specific gravity is 2·99.

1·3 grammes gave—

Silica,	·457	
From Alumina,	·028	
	·475	= 36·538
Alumina,		22·282
Ferric Oxide,		2·433
Ferrous Oxide,		16·009
Manganous Oxide,		·784
Lime,		1·249
Magnesia,		10·
Potash,		8·264
Soda,		·794
Water,		1·506
		99·856

Insoluble silica, 3·791 per cent. Possible impurity, oligoclase.

From Micaceous Gneiss.

6. The gneiss of the hill of Clach-an-Eoin (Yone), situated between the mouths of the Navir and the Borgie, in Sutherland, exhibits on its glaciated front a peculiarity of structure which I have not seen described. In feeble, comparatively very feeble development, something of the same kind is to be seen in the gneiss of Boggierow quarry near Portsoy,—at Strath Virick Bridge, near Arguish,—and at Innisbae, on the Dirrymore road in Ross-shire.

At the first, and possibly also at the second of these localities, the structure may be regarded as a mere modification, or a badly-developed instance of porphyritic arrangement in the felspathic portion of the stone. At Boggierow the crystals of the felspar, if crystals they be, are devoid of all edges and angles, appearing rather as kernels or nodules, of some half inch or so in size. Of these there is here no definite arrangement whatever,—they are promiscuously scattered throughout the mass.

As regards the size and want of angularity of the felspathic portions of the Innisbae rock, the above also holds; but there is here no promiscuous scattering —no absence of arrangement. These felspathic kernels lie in regular layers accordant with the micaceous lamination of the rock, following obediently that lamination where it has been crumpled *

This approaches, though it does not come up to,—it resembles, though it is really different from what is to be seen at Clach-an-Eoin.

The study of the Boggierow rock leaves the impression that the felspathic portion had attempted to arrange itself as crystals, or had been crystals, porphyritically disposed. Such a conclusion will hardly apply to the Innisbae rock; the felspathic matter is certainly not porphyritically disposed when it is confined to a regular arrangement in layers; and such a conclusion certainly will not apply at all to what obtains at the northern locality. First, it will not apply in *size;* the individual collections of felspathic matter, to which inches applied at the other localities, are here of the dimensions of feet and yards. Second, it will not apply as to *internal structure;* a certain amount of rough cleavage which is to be obtained in the first cases showed that each—all being much of a size—was to be regarded as an individual mass, of which the components were *its molecules;* here nothing like cleavage is to be got; the components are crystals, granules, plates, promiscuously agglutinated, and forming masses of greatly varying size. Thirdly, it cannot apply as to *shape;* there is here no trace of geometric form, for the masses are lenticular.

The strike of the rock is north by east and south by west; it stands nearly vertical; its bedding is well shown by the parallel disposition of its layers of black mica; it is singularly free from all plication; but, between the bedding of its mica sheets, there occur in marked abundance, but at quite irregular distances, parallel arrangements of the segregated felspar of the rock, disposed like the glands on a duct, or ganglia on a nerve, the enlargements being of ever-varying size.

In one respect the comparison with ganglia on a nerve is not satisfactory; the felspathic bands are generally not continuous, but the juxtaposition of the two micaceous layers which lately sheathed what I have represented under the figure of ganglionic enlargements, leads, in straight course, to the next, and not far separated lenticular mass.

There can be little room for doubt that this is a modified development of that segregatory process in virtue of which the felspathic material of gneissose rocks so frequently arranges itself in layers or bands. As these bands consist of a material more plastic than the less fusible quartz and mica, they are, in the ordinary case, when plicated, thinned off to nothing at the more compressed flexures, only to re-appear in ampler development among the loosened or more drooping folds. But at Clach-an-Eoin we have no plications to compress or

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* Something very close to this is given by COTTA as his description of typical porphyritic gneiss,—"In the otherwise uniform schistose mass there occur at intervals large egg-shaped crystals of orthoclase (sometimes amorphous), round which the foliated texture bends itself with a wavy sweep." Ruskin, in treating of the rock-structure of the Alps, gives an admirable drawing of such gneiss.

loosen; *and the portions of the rock where the felspar thins off are actually the least compressed of the whole. This is seen by the opening out of the micaceous layers there, and in the immediate vicinity.*

Can it be that the metamorphism—for it is a district of considerable though not extreme metamorphism—has rendered the more fusible material so plastic that cohesion has here been tugging hard to cause it to assume actually a spherical form, and has been baffled only by gravitation (acting before the rock was tilted), which flattened out the sphere into a lens-like shape,—or rather retained in a lens-like shape, that which without its action would, through the operation of cohesion, have assumed the form of a sphere?

But the description is as yet faulty. I have used the recognised geological term "lenticular" as the adjective altogether most applicable—but the relative proportions of these masses, which vary from the size of a goose's egg to that of a grampus, is a length about twice as great as their breadth. As they, however, thin away also somewhat as they merge into their connecting band, they present in section an appearance so similar to that of an eye, that it appeared to my fellow-workers, Dr Joass and Mr Dudgeon, that it would be most fitting that we should, meanwhile, designate what I have described as an *occulitic structure.*

The black mica, which so clearly defines the rock layers, is here Haughtonite.

Towards the north-east cliff of the hill it is to be found in plates of some inches in size; these plates protrude edgeways from the quartz veins of the rock, are much weather-worn, and have the colour and lustre of tarnished metallic lead. They are associated with garnet, rutile, ilmenite, and chlorite.

The colour of their cleavage surfaces is clove-brown; red-brown by transmitted light; they are uniaxial, or very-slightly biaxial.

Specific gravity (average of three specims), = 2·96.

1·3 grammes yielded—

Silica,	·453	
From Alumina,	·013	
	·466 =	35·846
Alumina,		21·539
Ferric Oxide,		4·467
Ferrous Oxide,		18·306
Manganous Oxide,		·307
Lime,		1·249
Magnesia,		8·076
Potash,		7·759
Soda,		·794
Water,		1·956
		100·299

Insoluble silica, 3·648 per cent.; possible impurity, quartz.

From Intrusive Veins in Gneiss.

7. The following specimen was found by Mr James Wilson of the Geological Survey, and I examined it at Professor Geikie's request.

It was imbedded in a very pale lavender almost white orthoclase, which forms a vein which in a semicircular curve cuts the schists to the north of the Kinnaird Head lighthouse.

The orthoclase is interesting not only from its rare colour, but also from its showing in an unusually distinct manner, the structure described by me in my paper on the felspars,—it is probably Descloizeaux' *microline.*

Radiated cleavlandite is imbedded in bundles of divergent crystals at the surfaces of the orthoclase; its colour is the same, or somewhat paler.

The mica is in foliæ of half an inch in size. It is black in mass, but when cleaved thin it has a fine, dark, grass-green colour. It is very slightly biaxial. It powdered with unusual facility, being brittle. Its specific gravity is 3·126.

1·2 grammes yielded—

Silica,	·42		
From Alumina,	·008		
	·428	=	35·666
Alumina,			17·947
Ferric Oxide,			7·191
Ferrous Oxide,			18·063
Manganous Oxide,			2·
Lime,			1·4
Magnesia,			1·5
Potash,			9·273
Soda,			3·81
Water,			3·2
			100·05

The portion examined seemed quite pure: the possible impurity was the felspar, in which it was imbedded.

This specimen is remarkable on account of the small quantity of magnesia which is present.

From Intrusive (?) Veins in Granite.

8. From the granite quarry of Cove, Kincardineshire. Occurs in veins, in elongated crystals, which lie frequently imbedded in and parallel to the

longer diagonal of crystals of muscovite. It calls for the exercise of some force to separate the plates of the two micas. This is somewhat singular, seeing that they are so seldom associated even in the same rock, not to say locality.

Colour very dark brown. Uniaxial, or axial divergence small.

1·3 grammes yielded—

Silica,	·431		
From Alumina,	·03		
	·461	=	35·469
Alumina,			18·798
Ferric Oxide,			4·611
Ferrous Oxide,			19·188
Manganous Oxide,			·643
Lime,			·904
Magnesia,			7·007
Potash,			8·188
Soda,			·238
Water,			4·97
			100·016

Possible impurity, muscovite.

The "glass" of this mineral was of a dingy green colour, slightly tinged with yellow.

The state of the oxidation and quantity of the iron was twice determined. First on ·4 grammes by hydrochloric acid and fluorspar; secondly, on ·1407 grammes by sulphuric acid and fluorspar, yielding identically the same amount.

From Exfiltration Veins in Granite.

9. A mass of fine-grained granite occurs on the west shore of Harris, opposite to Taransay, forming a point of land which lies intermediate between Nishibost and Borve.

This granite has many veins, plentifully studded with jet black crystals of this mica.

These crystals are here some inches in size, of somewhat unusual hardness, and of high lustre.

They are seemingly of great purity, though occasionally coated with a loose ochrey rust.

They are biaxial to the extent of 2° to 3°. Their gravity is 3·05.

1·3 grammes yielded—

Silica,	·445		
From Alumina,	·012		
	·457	=	35·154
Alumina,			16·704
Ferric Oxide,			5·961
Ferrous Oxide,			19·063
Manganous Oxide,			1·016
Lime,			·818
Magnesia,			7·461
Potash,			9·243
Soda,			1·259
Water,			3·133
			99·812

Possible impurity unknown.

From Exfiltration Veins in Syenitic Granite.

10. From an exfiltration vein in the so-called syenitic granite of Cnoc-dubh, about a mile east of Lairg, Sutherland.

The associated minerals in this vein are quartz, orthoclase, oligoclase, sphene, and Allanite. Colour dark green. Lustre greasy. No plate large enough and transparent enough to determine the optical properties could be got; nor could a portion large enough for determining the specific gravity be found.

On ·72 grammes—

Silica,	·245		
From Alumina,	·011		
	·256	=	35·555
Alumina,			16·694
Ferric Oxide,			1·883
Ferrous Oxide,			18·037
Manganous Oxide,			·694
Lime,			2·722
Magnesia,			8·472
Potash,			9·896
Soda,			·105
Water,			5·714
			99·772

Insoluble silica, 10·546 per cent. No fluorine; possible impurity, ortho- or oligoclase. Some lighter-green plates had a slight appearance of decomposition.

From Diorite.

11. For long I had fruitlessly endeavoured to procure specimens such as could be analysed of the black mica which occurs throughout the dioritic rocks of Banffshire, in some localities sparsely, in others in large amount.

In the summer of 1878, along with Mr Peyton, lately of Portsoy, I, however, by the merest chance obtained, on the west shore of the Bay of the Durn, a large mass thereof, consisting of interplated crystals: it apparently formed a part of a vein; it was attached to diorite, and passed somewhat into it.

The colour was brown, somewhat bronzy; the crystals, of about half an inch in size, were twisted among each other, and so had a glimmering, somewhat greasy lustre. Specific gravity 3·074.

On 1·3 grammes—

Silica,	·425		
From Alumina,	·018		
	·443	=	34·076
Alumina,			17·339
Ferric Oxide,			3·613
Ferrous Oxide,			18·703
Manganous Oxide,			·384
Lime,			3·23
Magnesia,			10·538
Potash,			6·78
Soda,			1·193
Water,			4·052
			99·905

Loss in bath, ·217 per cent.

12. The next specimens differ from the foregoing in containing more magnesia. They were obtained out of a granitic mass which lay on the south side of the road which runs along the side of Loch Stack, Sutherland. The mass lay towards the west end of the loch; it appeared to have fallen from the cliff on the north side of Ben Stack, but whether it was from an intrusive vein or from a band of metamorphic segregation could not be ascertained; it had much of the appearance of the former.

It was in plates of some inches in size; colour, brownish black; greenish on being crushed; lustre not very high.

The only associates were the quartz and felspar of the granitic vein. Specific gravity, 3·05.

1 · 3 grammes yielded—

Silica,	· 445		
From Alumina,	· 019		
	· 464	=	35 · 692
Alumina,			20 · 086
Ferric Oxide,			2 · 233
Ferrous Oxide,			14 · 011
Manganous Oxide,			1 ·
Lime,			1 · 895
Magnesia,			14 · 769
Potash,			7 · 381
Soda,			· 529
Water,			2 · 465
			100 · 058

Insoluble silica, 3 · 448 per cent. Possible impurity, quartz; no fluorine.

These micas were not all examined for fluorine, but it was not found in any of those which were examined.

HAUGHTONITE.

	S. G.	$\ddot{Si}$.	$\dddot{Al}_2$.	$\dddot{Fe}_2$.	$\dot{Fe}$.	$\dot{Mn}$.	$\dot{Ca}$.	$\dot{Mg}$	$\dot{K}_2$.	$\dot{Na}_2$.	$\dot{H}_2$.	Total.
Roneval,	3·03	37·16	15·	7·69	17·35	1·04	1·3	8·88	8·18	1·6	2·12	100·17
Capval,	3·07	36·81	15·22	7·61	17·35	·96	1·54	8·78	8·31	1·34	2·47	100·40
Loch-na-Muilne,	...	36·46	17·25	4·18	15·33	·54	·69	12·23	9·2	·66	3·39	99·92
Foinaven,	3·03	36·75	17·86	2·78	15·18	·42	·93	11·17	9·44	1·25	4·23	99·99
Rispond,	2·99	36·54	22·28	2·43	16·01	·78	1·25	10·	8·26	·79	1·51	99·86
Clach-an-Eoin,	2·96	35·85	21·54	4·48	18·31	·31	1·25	8·08	7·76	·79	1·96	100·33
Kinnaird Head,	3·13	35·67	17·95	7·19	18·06	2·	1·4	1·5	9·27	3·81	3·2	100·05
Cove,	...	35·47	18·8	4·61	19·19	·64	·9	7·01	8·19	·24	4·97	100·02
Nishibost,	3·05	35·15	16·7	5·96	19·06	1·02	·82	7·46	9·24	1·26	3·13	99·81
Lairg,	...	35·56	16·69	1·88	18·04	·69	2·72	8·47	9·9	·11	5·71	99·77
Portsoy,	3·07	34·08	17 34	3·61	18·70	·38	3·23	10·54	6·78	1·19	4·05	99·9
Ben Stack,	3·05	35·69	20·09	2·23	14·01	1·	1·89	14·77	7·38	·53	2·47	100·06

The two micas which follow, though probably belonging to the same species, are, on account of their differing somewhat from the others, meanwhile placed apart.

13. The first occurs on the west coast of Sutherland, about a mile and a-half south of the lighthouse at Cape Wrath.

In two of the small indentations of the coast, beds of the red conglomerate are to be seen covering the tilted strata of the hornblendic gneiss. The more southerly of these little bays may be additionally recognised by several striking granitic veins which intersect the dark hornblendic rock. On the north side of an indentation immediately to the south of this, a bronzy mica is to be found, plentifully interspersed in a brownish white felspar (oligoclase).

Its physical characters are the same as those of the micas already noted. It is in rich dark-brown crystals of an inch in size. It seemed slightly altered at the edges, but these were cut away from the portions analysed; still from the loose state of the rock I conceive that alteration and peroxidation may have extended to the centre of the crystals, and that specimens from a greater depth will altogether accord with Haughtonite.

Its sole associate was the felspar.

1·3 grammes yielded—

Silica,	·44		
From Alumina,	·004		
	·444	=	34·153
Alumina,			14·837
Ferric Oxide,			10·961
Ferrous Oxide,			13·474
Manganous Oxide,			1·384
Lime,			1·809
Magnesia,			10·307
Potash,			7·93
Soda,			2·136
Water,			2·8
			99·971

14. The following does not accord with the others as regards the quantity of alumina, which is here much larger; in other respects it seems the same. It occurs in comparatively small amount on the southern slopes of the hill of Clashnaree, in Clova, Aberdeenshire.

It is associated with red andalusite, labradorite, fibrolite, and margarodite, which minerals occur not in veins, but in layers or bands of the rock. The mica is of a brilliant lustre, and a bronzy-brown colour. A sufficiency for analysis was got with much difficulty, and it may not have been altogether free from gaugue, and possibly also from labradorite.

1·2 grammes yielded—

Silica,	·448		
From Alumina,	·02		
	·468	=	39·
Alumina,			25·096
Ferric Oxide,			6·514
Ferrous Oxide,			9·801
Manganous Oxide,			·666
Lime,			·933
Magnesia,			6·166
Potash,			7·084
Soda,			1·626
Water,			3·466
			100·332

BLACK MICAS.

	$\dddot{\text{Si}}$.	$\dddot{\text{Al}}_2$.	$\dddot{\text{Fe}}_2$.	$\dot{\text{Fe}}$.	$\dot{\text{Mn}}$.	$\dot{\text{Ca}}$.	$\dot{\text{Mg}}$.	$\dot{\text{K}}_2$.	$\dot{\text{Na}}_2$.	$\dot{\text{H}}_2$.	Fl.	$\ddot{\text{Ti}}$.	Totals.
Biotite—													
Glen Urquhart,	38·69	17·66	·26	12·95	...	1·16	17·54	8·92	·13	2·14	·52	...	99·96
Loch Laggan,	39·5	15·04	·24	10·23	·75	1·4	18·46	9·37	·62	3·21	·73	...	99·55
Shinness,	39·77	16·68	·65	6·73	·62	2·2	20·92	6·5	·48	5·4	...	...	99·95
Glen Beg,	39·46	16·45	·39	10·	·53	1·59	19·	8·22	·26	3·34	·32	...	99·56
Hillswick,	39·8	14·19	2·59	11·78	·24	·1	18·32	8·43	2·11	2·52	·56	...	100·64
Milltown,	40·31	12·58	1·81	3·35	·38	7·58	21·	6·56	·95	5·74	n.d.	...	100·25
Haughtonite—													
Roneval,	37·16	15·	7·69	17·35	1·04	1·3	8·88	8·18	1·6	2·12	...	...	100·17
Capval,	36·81	15·22	7·61	17·35	·96	1·54	8·78	8·31	1·34	2·47	...	...	100·40
Loch-na-Muilne,	36·46	17·25	4·18	15·33	·54	·69	12·23	9·2	·66	3·39	...	...	99·92
Foinaven,	36·75	17·88	2·78	15·18	·42	·93	11·17	9·44	1·25	4·23	...	...	99·99
Rispond	36·54	22·28	2·43	16·01	·78	1·25	10·	8·26	·79	1·51	...	...	99·86
Clach-an-Eoin,	35·85	21·54	4·48	18·31	·31	1·25	8·08	7·76	·79	1·96	...	...	100·33
Kinnaird Head,	35·67	17·95	7·19	18·06	2·	1·4	1·5	9·27	3·81	3·2	...	...	100·05
Cove,	35·47	18·8	4·61	19·19	·64	·9	7·01	8·19	·24	4·97	...	...	100·02
Nishibost,	35·15	16·7	5·96	19·06	1·02	·82	7·46	9·24	1·26	3·13	...	...	99·81
Lairg,	35·56	16·69	1·88	18·04	·69	2·72	8·47	9·9	·11	5·71	...	...	99·77
Portsoy,	34·08	17·34	3·61	18·70	·38	3·23	10·54	6·78	1·19	4·05	...	...	99·9
Ben Stack,	35·69	20·09	2·23	14·01	1·	1·89	14·77	7·38	·53	2·46	...	...	100·06
Foreign do.—													
16. Brand,	37·18	17·53	6·20	15·35	·31	·79	9·05	5·14	2·93	3·62	...	2·47	100·57
17. Brand,	37·06	16·78	6·07	15·37	tr.	·57	9·02	5·96	2·86	3·77	...	3·64	101·1
18. Hartzburg,	36·17	18·09	8·7	13·72	...	·52	11·16	7·59	tr.	2·28	·36	...	98·59
Schwarzwalder,*	33·6	15·	4·99	19·29	...	3·36	11·62	7·53	·51	4·58	tr.	...	100·48
Tyrberger,†	35·5	18·01	9·24	12·11	tr.	3·02	10·86	9·18	1·93	...	...	...	99·85
Cape Wrath,	34·15	14·84	10·96	13·47	1·38	1·81	10·31	7·93	2·14	2·8	...	...	99·79
Clova,	39·	25·1	6·51	9·8	·67	·93	6·17	7·08	1·63	3·47	...	...	100·33
Lepidomelane—													
Achadhaphriz,	40·38	12·11	14·53	3·03	3·17	1·03	13·	7·13	1·8	3·57	...	...	99·72
Tongue,	40·08	12·41	13·47	2·67	·62	1·08	14·66	7·57	2·15	5·29	...	...	99·99

In the above table I have inserted three analyses by other observers—16, 17, 18—from DANA's list, and two from a more recent source.

A condensation of this table gives the following averages of the composition of these micas,—from which averages the oxygen ratios are calculated; the Irish lepidomelane being the average of Dr Haughton's analyses :—‡

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* *Hebenstreit.* From gneiss, with axial angle small.

† *Hebenstreit.* From the granite of the Tyrberger water-fall; specific gravity, 3·07. *Zeitschrift für Krystallographie und Mineralogie, Zweiter Bund, erstis heft.*

‡ One or two of the Haughtonites were not included in calculating the average, their analysis having been very lately executed; as they agreed with the others, their exclusion does not effect the result.

Biotite.

		Oxygen.		
Silica,	39·35	20·99	20·99	21
Alumina,	16·46	7·67	7·78	8
Ferric Oxide,	·38	·11		
Ferrous Oxide,	9·98	2·28	14·95	15
Manganous Oxide,	·47	·1		
Lime,	1·3	·4		
Magnesia,	18·98	7·59		
Potash,	8·25	1·4		
Soda,	·37	·08		
Water,	3·5	3·1		

Haughtonite, Scottish.

		Oxygen.		
Silica,	35·93	19·16	19·16	19
Alumina,	18·06	8·41	9·78	10
Ferric Oxide,	4·55	1·37		
Ferrous Oxide,	18·06	3·8	12·67	12·5
Manganous Oxide,	·81	·18		
Lime,	1·49	·42		
Magnesia,	9·07	3·63		
Potash,	8·49	1·44		
Soda,	1·12	·29		
Water,	3·27	2·91		

Haughtonite, Foreign.

		Oxygen.		
Silica,	35·9	19·1	19·1	19
Alumina,	17·08	7·96	10·07	10
Ferric Oxide,	7·04	2·11		
Ferrous Oxide,	15·17	3·36	12·34	12·5
Lime,	1·65	·47		
Magnesia,	10·34	4·14		
Potash,	7·08	1·2		
Soda,	1·64	·42		
Water,	2·85	2·75		

Lepidomelane, Scottish.

		Oxygen.		
Silica,	40 · 23	21 · 46	21 · 46	21 · 5
Alumina,	12 · 26	5 · 71	9 · 91	10
Ferric Oxide,	14 ·	4 · 2		
Ferrous Oxide,	2 · 85	· 63	12 · 43	12 · 5
Manganous Oxide,	1 · 89	· 42		
Lime,	1 · 08	· 6		
Magnesia,	13 · 83	5 · 33		
Potash,	7 · 35	1 · 25		
Soda,	1 · 97	· 51		
Water,	3 · 93	3 · 49		

Lepidomelane, Irish.

		Oxygen.		
Silica,	36 · 62	19 · 53	19 · 53	20
Alumina,	17 · 5	8 · 15	15 · 38	15 · 5
Ferric Oxide,	24 · 09	7 · 2		
Ferrous Oxide,	2 · 70	· 6	6 · 89	7
Manganous Oxide,	1 · 31	· 3		
Lime,	1 · 35	· 4		
Magnesia,	4 · 81	1 · 92		
Potash,	8 · 7	1 · 48		
Soda,	· 31	· 08		
Water,	2 · 37	2 · 11		

These ratios show, firstly, that, as is usual in the micas, the oxygen ratio of the bases is, in each of the above, in excess of that of the silica.

Secondly, that the ratios of the sesquioxides to the protoxides in Biotite and Irish lepidomelane are inverted; being in Biotite only half of that of the protoxides, while in the Irish lepidomelane it is twice as great as that of the protoxides.

The foreign and Scottish Haughtonite is evidently the same compound; and this is one which stands intermediate between Biotite and Irish lepidomelane; the oxygen of the protoxides and sesquioxides being in Haughtonite more nearly equal in amount than in either of the other species.

And what I have called the Scottish lepidomelane is, as regards the balancing of the oxygen of the bases, more closely associated with Haughtonite than it is with the Irish lepidomelane.

That which really, however, constitutes the distinguishing features of these micas is the state of oxidation or the iron.

In Biotite the relative proportion of ferrous to ferric oxide is as 25 to 1; in Scottish Haughtonite as 4 to 1; while in lepidomelane these proportions are altogether inverted, being in the Scottish lepidomelane as 1 to 5, and in the Irish as 1 to 9.

A consideration of the foregoing tabulation also makes manifest the following additional chemical distinctions between these minerals.

Biotite differs from Haughtonite in containing an amount of magnesia which is twice as great as that of the protoxide of iron; the iron also is in Biotite present almost solely in the ferrous state; while in Haughtonite the relative proportions of the above protoxides are fully more than inverted, there being also a considerable quantity of iron in the ferric state.

In all, the alkalies and water are present in about the same amount; nor do the proportions of the silica and alumina differ largely.

Altogether, there can be no question that the substance standing in an intermediate position in the table is distinct; and I conceive that it is most fitting that it should be named after the gentleman who first analysed the black micas of Ireland, and so established the specific individuality of the mineral which stands next to this in the system,—happily fitting also, seeing that it exists as the distinctive mineral of one of the varieties of granite, a rock in the study of which Dr HAUGHTON has for long been closely engaged.

The geognostic position of these minerals is for the most part well marked.

As the plates or crystals in which they are found are usually of extreme tenuity, it is not easy to obtain, under the ordinary circumstances of local collecting, a sufficiency for analysis, and hence the unimpeachable evidence afforded thereby is not great in amount; nor is it, in the absence of characteristic specimens, easy to distinguish between the three species. The instances, however, that I shall adduce in addition to those analysed, have, for the most part, been established by partial examination or fairly satisfactory proof.

Every case in which there is doubt will be notified.

The four first analyses show Biotite to occur in association with granular limestone. In Glen Urquhart, in a most peculiar granitiform belt in the centre of the lime;* also, near Milltown, in a singular rock, in association with edenite and Wollastonite; at Loch Laggan, imbedded in chlorite, in the lime; at Shinness, immediately in contact with sahlite, &c., at the junction of the lime with the inclosing rock; at Glen Beg, in contact with two known and a new felspar;—these may together have formed a belt similar to that at Urquhart. Additional limestone localities are the following:—In the most westerly of the two great beds which traverse the North of Scotland, I only know of it at Redhythe, where it is associated in the limestone itself with talc, pyrrhotite, and rutile. In the most easterly it occurs at Glen Gairn, with prehnite and coccolite, at

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[*] This peculiar granitiform belt I have seen cutting limestone strata elsewhere in Scotland,—as at Laggan near Dulnan Bridge, Inverness-shire; and Boultshoch, in Aberdeenshire. This belt always carries Biotite, and the felspar in two of these cases has upon analysis proved to be Andesine.

the junction of the bed with the gneissose matrix. At Crathie, in similar association. In the great bed which traverses the country down Dee side, it occurs here and again, as in the openings on the Leac Ghorm Hill, in Boultshoch quarry near Abergeldie, and in Craigs, Muir, and Midstrath quarries—in all being imbedded in a granitic belt very similar in appearance to that at Glen Urquhart; this belt is, in the three last quarries, composed of little quartz, much fatty lustred white orthoclase, and little of the mineral itself.

It is likewise found in the limestone of Froster Hill, near New Meldrum; along with blue malaccolite, near lime, at Allt-Cailleach, Coyle Hills; along with zoisite, pyrrhotite, sahlite, and the usual lime minerals, at Dulnan Bridge south of Grantown; and along with similar minerals and cinnamonstone at Allt-na-Gonolan, in the same neighbourhood—at both localities in limestone.

Its occurrence with ripidolite at Hillswick, near the junction of what has been called hornblendic gneiss with micaceous rocks, is somewhat exceptional; but that first-named rock, which I shall elsewhere describe, is new to me.

Biotite is thus seen to occur generally associated with granular limestone. This is probably also the dark mica which occurs as an accessory mineral in hyperyte and tufa. It is nowhere associated with another mica.

Passing to Haughtonite, we find it, in the specimens analysed, a component of granitic veins, whether these be intrusive or exfiltrative. Extending the evidence, it is to be noted as occurring in specimens equally characteristic with the above, in Rubislaw, Anguston, Sclattey, and other quarries in the "grey granite," and the large, distinctive crystals are always in the veins.

At Blirydrine, Brathans, and many other places, it is seen in the felspathic bands of the gneiss.

In these situations it may be regarded as replacing muscovite, which very rarely, as at Cove, accompanies it. *In every case where it occurs in exfiltration veins, oligoclase is also present;* less frequent associates are sphene, Allanite, and in one locality (Anguston) ilmenite; what may be called chance associates are beryl, apatite, tourmaline, and garnet.

But besides its position in the exfiltration veins of the grey granite, it goes largely to form the mass of that rock itself. If the word granite be confined to a compound of quartz, orthoclase, and muscovite, then must "grey granite" lose all title to the name; for though quartzose in spots, as a rule it contains comparatively little quartz, hardly any muscovite, and not the excess of orthoclase normal to granites,—being composed in greatest bulk of oligoclase, quartz, and Haughtonite, with smaller quantities of orthoclase. The distinctive feature of the rock is the large quantity of this black mica.

In the ascertaining the nature of the dark mica of grey granite, it will not suffice to evade the trouble of picking out the minute scales from the general mass of the rock, by making use, instead thereof, of a portion of those curious dark micaceous patches which so frequently occur in grey granite—called *neres* by the quarrymen.

These somewhat kindey-shaped masses most frequently show an angularity of form,—they also almost invariably have the dark mica, which is their chief constituent, arranged in a laminated manner, parallel to their longer diagonal, whatever be the position of that diagonal,—whether horizontal or vertical. These facts alone would lead us to regard them as being not concretions in the rock, but *fragments of gneiss;—unresolved,* if the word is admissible—unresolved or residual fragments of the gneiss, the metamorphosis of the general mass of which resulted in the granitic paste which now holds these fragments imbedded.

Till however the actual nature of these "neres" is placed beyond question, any evidence derived from them must be received with caution.

Examination, to the extent of ascertaining the relative proportions of the two oxides of iron in the minute black scales of the rock itself, shows that Haughtonite is *the* mica of the grey granites of Aberdeenshire.

I have only lately been able to offer analytical evidence as to its second mode of occurrence; namely, as *the* mica which occasionally replaces hornblende in diorite.

Typical diorite has no mica. In perhaps the most important mass of diorite in Scotland, that namely which, showing itself first in the north in the vicinity of Portsoy, stretches up the country as far as Morven, the character of the rock changes repeatedly and even suddenly to a marked extent.

This diorite, however, which is most simple in its composition in its northern portions, I have elsewhere shown to be not typical even there; for *labradorite* is there, as it is throughout, the species of felspar characteristic of the rock; indeed, it is the only felspar to be found therein.

The repeated changes which take place in the rock seem to result from the substitution of augite and Haughtonite for hornblende in the first place,—of hypersthene for that Haughtonite in the second,—and from the removal of all the chief ingredients, except labradorite and Haughtonite, in the third. Marked as such changes are, and absolutely dissimilar as are the extremes of such rocks, the gradual steps of the transmutation can be detected, leading to the conviction that all must be regarded as but varieties of one great rock mass.

Such has been the conclusion of MACCULLOCH, of CUNNINGHAME, and of NICOL, who unite in laying them down with one colour,—that colour indicating an igneous rock of the granitic type.

Of this, however, there is, as I have pointed out in my paper on hornblende, considerable doubt; I therein considered the amount of information to be derived from the augitic and hornblendic ingredients of the rock, and we have now to see what light may be thrown upon it by its mica. The chief difficulty lies in connection with the question of the whole rock so coloured constituting one mass, unless it be admitted that the rock has at different points suffered a varying amount of metamorphism.

The rock where first seen, near the old battery at Portsoy, consists of a grey striated labradorite and a grey brown (red by transmitted light) hornblende, with extremely rarely a speck of menaccanite. Here the rock is of a very coarse grain; it carries occasional veins of labradorite, and in these only is Haughtonite here to be seen. As this rock passes to the eastward, the labradoric ingredient increases in quantity, the hornblende becomes light green and uralitic, and the rock is altogether much finer in structure. This is, however, the only change which can be here detected, and an examination of the rock in all its relationships, and a consideration of all its appearances, leaves no room for doubt that it has a stratified structure, and is here of a metamorphic nature.

Upon the west side of the Bay of Durn, however, a rock of a somewhat similar nature to this appears, the two being separated by bands—well seen at the Harbour of Portsoy—which have a minute crystalline and perfectly schistose structure.

The evidences as to the rock on the Durn Shore being a metamorphosed, and not an intrusive mass, are by no means so clear; and its constituent minerals also differ considerably.

The small amount of felspar here visible is, indeed, the same; but the hornblende has given place, apparently entirely, to a mixture of augite and hypersthene, both being in minute crystals, with rare and minute occurrences of Haughtonite. Now it is the union as laid down in geological maps, of this rock with that previously described, which has not been, and, from the covered-up state of the country inland, probably cannot be proved; so that here at the outset, as regards this locality at least, it cannot be shown that the hornblende is *replaced* by augite and Haughtonite, for the rock may be intrinsically different—may, in fact, be of the nature of a non-chloritic diabase.

In the more southerly portions of this last rock, and also to the eastward, a gradual increase in the quantity of Haughtonite and disappearance of the hypersthene is obvious; and when we get further south, the rock which appears to be the continuation of one or other, or perchance of both of the above, becomes pervaded with exfiltration veins, in which the Haughtonite again gives place to true hypersthene. This is to be seen on the west slopes of Craig Buiroch and at Retannach. The occurrence of a labradoric pitchstone gives countenance to the view that the rock is here volcanic.

As a rule, Haughtonite and true hypersthene do not occur in the same locality; the rock on the west side of the Bay of the Durn, and that on the north side of Barra hill, however, contain both. Pyrite is a rare accessory at the first, pyrite and menaccanite at the second of these localities.

In many localities the augite and hypersthene both give place to the mica, the felspar only remaining the same; these transmutations occur repeatedly. At the Barry granite quarry near Knock the mica is hardly to be seen, at the Bin of Huntly augite and hypersthene replace it entirely. Where the rock appears on the south side of the Burn of Craig, near Towanrieff, the labradorite has again the mica as its sole associate. A loose block or two of a similar rock occurs at New Merdrum near Rhynie; in these the crystals of both minerals are over an inch in size.

Up the valley of the Blackwater, a bed of diorite, with occasional specks of doubtful hypersthene, or in its place of a black mica, is to be seen. There can be little doubt that it is the same belt of rock which reappears at Glenbucket and Colquhanny, and here hornblende, with a little Haughtonite, is again present, menaccanite and sphene also occurring.*

The lithological position of the new mineral is, therefore, clearly defined and altogether distinct from that of Biotite; they never occur together, or replace each other in the same rocks.

Of lepidomelane this cannot, to the full at least, be said.

Though I have never found it in association with Haughtonite, one of the specimens analysed was taken from an exfiltration vein in a rock very similar to that which at Lairg carried the Haughtonite; the other lay bedded in the felspathic belt of a hornblendic gneiss.

It is possible that lepidomelane may also be the dark mica of other gneisses,—*ex grege*, of the peculiarly bronzy gneiss of Tiree, which carries garnet.

Chemically quite different from the former micas, this is not clearly separated from the last in its modes of occurrence, being found, though only once, in an exfiltration vein. Still in Scotland it does not, as in Ireland, pertain to the granites, being here probably solely a gneissic mica.

Be this as it may, these geologic relations go to establish very clearly the specific individuality of Haughtonite.

Two important distinctive properties remain to be noticed,—crystalline form, and chemical features.

---

* Localities in which it is doubtful whether the black mica is this species or Biotite are the following:—

At Badnagauch on the Deskery there is a rotting syenite, which is riddled with exfiltration veins composed of large crystals of labradorite and hornblende, with a hydrated Biotite (?), menaccanite, sphene, and Allanite as accessories.

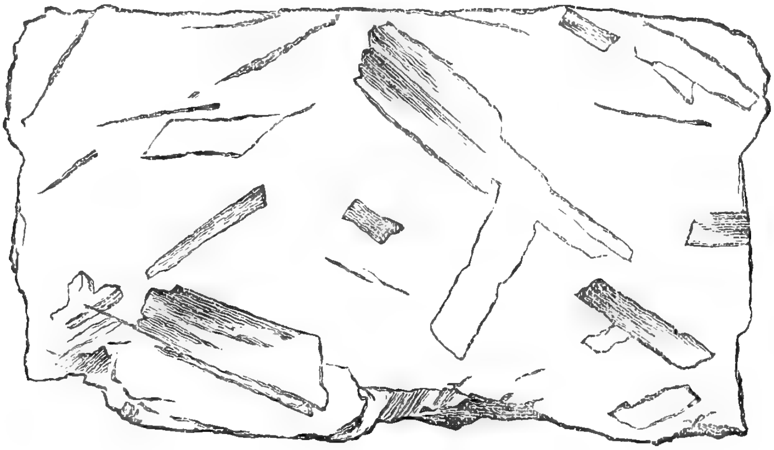
In the hyperite of Scuir na Gillean in the Cuchullins, and of Halival in Rum, a black mica is rarely seen, which is most probably Biotite.

Scales of a dark brown uniaxial mica, which occur in tufa at Kinkell and Kincraig in Fife, I also set down as Biotite. Haughtonite probably is the brown mica which, in somewhat small quantity, is found in the andalusite layers of the gneiss of Clashnaree, Glendarff, and other hills of the Clova district. The associates here being andalusite, quartz, fibrolite, and labradorite. The composition of the mineral from this locality does not altogether accord with that of the generality of specimens, and its occurrence in gneiss is somewhat exceptional.

I have noted, as regards the optical properties of Haughtonite (where its extreme opacity permits of observation), that it was found to be biaxial, though only to a small extent—2° to 3°. It is not this fact so much as the *habit* of its plates, which induces the belief that it is *orthorhombic* in form.

Distinct, or at least free, crystals I have not met with. In many instancesit is found in plates devoid of regular form and definite appearance: this is the case at Roneval, Nishibost, Rispond, and Clach-an-Eoin; but at most of the localities in which it occurs in exfiltration veins in granite, the crystals are disposed in lengthened, radiating, somewhat fan-shaped arrangements, with oblique terminations; these crystals are frequently three or four inches in length, by a fourth of an inch in width: they so occur at Lairg, Rubislaw, Cove, the graphic granite and the adjacent granitic vein at Portsoy, at Blirydrine, and at Craig Burn, near Rhynie.

The accompanying sketch of a Craig specimen, expresses a not unusual appearance.



The peculiarity of the association with the muscovite of Cove has already been noted.

Before the blowpipe, the three species function differently, though to but a slight extent. All give with fluxes the iron reaction,—Biotite to the smallest, Haughtonite to markedly the largest extent. All fuse to a black magnetic bead,—Biotite with ease, Haughtonite with considerable difficulty,—lepidomelane, again, standing intermediate. The Biotite bead is but feebly magnetic; that of lepidomelane distinctly so; that of Haughtonite powerfully so.

Under the breath of the blowpipe flame the plate of Biotite, even if brown, whitens; that of lepidomelane pales; that of Haughtonite, if of a pale tint, or however black, becomes still blacker from increased opacity.

Under the action of acids, thin scales of the three substances are affected in the same order. When treated in the cold with hydrochloric and sulphuric acids, it is found that the former acid decomposes all; leaving scales of glistening silica in times which bear for the three, as arranged B.L.H., about the proportions of 1, 2, and 4. Sulphuric acid splits up the larger flakes into fungoid masses, accomplishing the same decomposition in times about 3, 5, and 9. When *gently heated,* however, the action of the sulphuric acid overtakes the more immediate action of the hydrochloric, the thorough decomposition being accomplished by the former in a considerably shorter time.

As might be expected from the large quantity of ferrous oxide in its composition, Haughtonite is subject to change on exposure.

At the one locality of Nishibost, the edges of the foliæ are covered with a bright red rust; elsewhere there is the development of first a dark green, and ultimately of a light green colour; the foliæ at the same time becoming friable and talcose;—the incipient change is well seen at Lairg, in Sutherland, the completed one at Blirydrine, Kincardineshire.

When it occurs as the cryptocrystalline constituent of granites and granitites, there can be little doubt that the peroxidation of the mineral is a chief cause of the rotting and disintegration of these rocks.

Granites, with feeble cohesion of their parts to a considerable depth, and which crumble rapidly into fine gravels, are to be seen at the south-east foot of Morven, and along Culbleen in Aberdeenshire. At Strontian in Argyle, whole banks of such gravel have to be dug through before anything like rock is reached. The springs of these districts are highly chalybeate: the changed mica has become bronzy or ochre-coloured, and talcose to the sense of touch. Peroxidation is in such cases the agent of waste.

One other question remains to be considered: seeing that the marked distinction between Haughtonite and lepidomelane lies in the state of oxidation of the iron, may the latter mica not be merely weathered or peroxidised Haughtonite?

As regards the Achadhaphriz and Ben Bhreck specimen, the answer is a distinct negative; from both localities the specimens were perfectly unaltered. The Achadhaphriz block had been broken up but a few days before the plates were removed from it; the Tongue boulder was split up by dynamite immediately before the collecting of what was analysed; and the associated minerals were all unchanged.

Altered (?) Black Mica.

From Exfiltration Veins in Syenite.

The exact nature of the specimens now to be described it is not easy to assign, as they may have undergone more or less change.

They occur in the rocky bank of a road-cutting, which had been made only about a year before the writer obtained the specimens; this rock cutting was about 20 feet in depth, and it was nearly at this greatest depth that the specimens were gathered. The locality is near the farm of Badnagauch, on the Deskery, in Aberdeenshire. The rock is the syenite of Morven, here much decomposed—being almost gravelly. Through this rock numerous anastimosing exfiltration veins occur; there is also an intrusive porphyry vein. The exfiltration veins had not suffered nearly so great an amount of change as the rock mass; indeed, except as regards the mica, there was little or no change in them. They contained large crystals of dark-green hornblende; large and finely-shaped crystals of labradorite, a few, apparently, of muscovite; granules, the size of peas, of menaccanite; foliæ of the mineral in question of about an inch in size; sphene and Allanite rarely. None of these minerals, with perhaps the exception of the mica, showed any appearance of change. It was in dark-brown, rather dull crystals, which in parts were somewhat softened and bronzy; the amount of change did not, however, appear to be great. The crystalline foliæ were somewhat loose. The specific gravity, taken on the mineral in its ordinary state, was 2·63 to 2·645; after being boiled to expel air it was 2·845.

1·302 grammes yielded—

Silica,	·42		
From Alumina,	·01		
	·43	=	33·026
Alumina,			13·167
Ferric Oxide,			26·075
Ferrous Oxide,			2·009
Manganous Oxide,			·153
Lime,			1·634
Magnesia,			4·831
Potash,			4·02
Soda,			1·161
Water,			13·882
			99·95

Was apparently pure. It contained no fluorine. The portions which appeared to have suffered some change were, as far as possible, cut away.

It lost in bath 5·731 of this water; the greater amount of this was lost in half an hour—the whole in half a day.

This composition is unquestionably nearer to that of lepidomelane than to Biotite; indeed, it is like a hydrated lepidomelane. The writer is disposed, however, to regard this as a fortuitous resemblance. It is difficult to believe the mineral to be merely a hydrated mica; these are not prone to excessive alteration, and the duration of the exposure could hardly have been sufficient to have effected any marked change. If it be a hydrated mica the amount of change is much greater than mere appearance would indicate, and care was taken to exclude, as far as possible, the altered portions. It may be an altogether different substance, intermediate between Voightite and Jollyite.

PIHLITE.

This species, hitherto unrecognised as British, is possibly not uncommon. Probably it is the chief material of the very peculiar schistose rock, which, plentifully studded with imbedded crystals of andalusite, forms the trough of the small sandstone basin of Lumsden and Kildrummy.

A very similar rock, only carrying crystals of actynolite instead of andalusite, occurs stretching from north of Mulben up the valley of the Burn of Achanachy. The rock of the first of these localities is largely quarried in the Coreen hills and in Glen Mid Clova, being used in the district as a paving, and also to a smaller extent as a building stone.

It is, doubtless, due only to the perfect seclusion of the district that the peculiar excellences of this rock are elsewhere unknown, seeing that it possesses qualities which fit it for its use as a paving stone, which are superior to those of both Caithness and Forfarshire.

Splendidly bedded, and with a most convenient dip, it can with the greatest possible facility be raised in slabs of large dimensions, of any required thickness, from an inch to a foot or more.

Quarried on the very summit of a hill, the trouble from water is so small that the little that occurs is actually stored for drinking purposes, and the carriage is aided by gravitation through a descent of some 900 feet.

The stone itself, being in its general mass formed of a material which yields to blows, is readily cut and fashioned; but this material, being acted upon by atmospheric agencies with extreme tardiness, "resists exposure;" while, inasmuch as its softer mass is everywhere studded with closely-packed crystals of one of the hardest mineral bodies known, it long resists the wear and tear of friction; and, as these enduring crystals project above the softer portions of the stone, slipping on its surface is noways to be feared.

The flags are, moreover, full of beauty. The micaceous particles which form the layers are arranged not in flat, but in minutely undulating disposition; they reflect a tremulous lustre, something between a nacreous glimmer and a silver sheen, while the dark brown of the andalusite crystals stipples this with a peculiarity which is quite unique.

The writer was formerly acquainted with a gentleman whose most successful research in geology consisted in his once having discovered "an unquestionable specimen of petrified maggots" in a pigstye, and whose faith therein was only slightly shaken after a dire amount of argumentation. Had he cast eye on one of these slabs, he would, in all probability, have believed in petrified maggots to the end of his days.

The specimens of this mineral which were analysed were got in North Glen Clova, where it is somewhat rare. They were specially selected on account of their being much lighter in colour, and hence apparently purer than those ordinarily procurable. This lightness of colour might, however, be due to incipient weathering. In appearance they were very similar to the paragonite of Monte Campione; indeed, they were supposed to be that mineral. They were scaly in structure and cream-coloured; soft and somewhat unctuous when rubbed along the lamination of the scales, but rough when rubbed across it.

They contained throughout their mass minute almost invisible crystals of magnetite; these were separated, it is believed absolutely, by crushing, repeated edulcoration, and sifting with a magnet.

The mineral absorbed ·579 per cent. of moisture. When slightly heated in powder before the blowpipe, there was a slight decrease in bulk and the assumption of a brown colour; when highly heated the contraction is very marked, and the powder agglutinates and shows traces of vitrification, the original colour being restored.

The two specimens analysed differed very slightly in appearance.

	On 1·3185 grammes.	On 1·584 grammes.
Silica, . . .	58·323	61·1
Alumina, . . .	26·455	26·516
Ferrous Oxide, . .	2·29	2·556
Lime, . . .	·467	·669
Magnesia, . . .	·568	·694
Potash, . . .	5·973	n. det.
Soda, . . .	1·688	n. det.
Water, . . .	4·847	4·23
	100·611	

Insoluble silica of first, 1·842 per cent.; of second, 1·584 per cent. Possible impurity, magnetite or quartz.

II.—*General Theorems on Determinants.* By THOMAS MUIR, M.A.

(Received 6th March 1879.)

§ 1. The rows of a determinant of the n^{th} order having been separated into two sets, one containing the first p rows and the other the rest, if each minor of the p^{th} degree formed from the first set be multiplied by a minor, called its complementary, formed from the second set, and the result have its sign chosen in accordance with a certain law, it is well known as an elementary theorem that the aggregate of the products thus obtained is equal to the original determinant.

This suggests the inquiry as to the possible existence of a corresponding theorem in the case where the two sets of rows, instead of being contiguous, overlap each other. On a review of the properties of determinants it is found that what may be considered one case of such a theorem is already known, viz., the case in which the first set includes all the rows except the last, and the second set all the rows except the first. Taking a determinant of the fifth order—

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{vmatrix} \quad \text{or} \quad D(a_{15})$$

this special theorem is

$$(a_{11}\,a_{22}\,a_{33}\,a_{44})\,(a_{22}\,a_{33}\,a_{44}\,a_{55}) - (a_{12}\,a_{23}\,a_{34}\,a_{45})\,(a_{21}\,a_{32}\,a_{43}\,a_{54}) = \begin{vmatrix} a_{22} & a_{23} & a_{24} \\ a_{32} & a_{33} & a_{34} \\ a_{42} & a_{43} & a_{44} \end{vmatrix} D(a_{15}),$$

or, in its usual form,

$$\begin{vmatrix} A_{11} & A_{15} \\ A_{51} & A_{55} \end{vmatrix} = \begin{vmatrix} a_{22} & a_{23} & a_{24} \\ a_{32} & a_{33} & a_{34} \\ a_{42} & a_{43} & a_{44} \end{vmatrix} D(a_{15}) \qquad . \; . \; . \; (a)$$

where it has to be observed that in the right-hand member the original determinant is now accompanied by a factor, and that this factor is the minor common to all the determinants on the left.

The general theorem which has been found to include this is as follows :—

In a determinant of the n^{th} *degree, if the rows from the* 1^{st} *to the* q^{th} *inclusive and the rows from the* p^{th} *to the* n^{th} *inclusive be taken; and if a minor of the* $(q-p+1)^{th}$ *degree be chosen from the rows common to these two sets; and if from the first set each minor of the* q^{th} *degree containing the chosen minor be multiplied by the minor which contains both the complementary of the former and the chosen minor; and if the sign* $(-1)^s$ *be prefixed to the product,* s *being the sum of the numbers indicating the rows and columns from which the first factor is formed increased by* $q-p+1$ *for every such number greater than* q *: then the sum of the products thus obtained is equal to the product of the chosen minor and the original determinant.*

Let

$$\begin{vmatrix}
a_{11} & a_{12} & a_{13} & \cdots & a_{1p} & \cdots & a_{1q} & \cdots & a_{1n} \\
a_{21} & a_{22} & a_{23} & \cdots & a_{2p} & \cdots & a_{2q} & \cdots & a_{2n} \\
a_{31} & a_{32} & a_{33} & \cdots & a_{3p} & \cdots & a_{3q} & \cdots & a_{3n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{p1} & a_{p2} & a_{p3} & \cdots & a_{pp} & \cdots & a_{pq} & \cdots & a_{pn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{q1} & a_{q2} & a_{q3} & \cdots & a_{qp} & \cdots & a_{qq} & \cdots & a_{qn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{n1} & a_{n2} & a_{n3} & \cdots & a_{np} & \cdots & a_{nq} & \cdots & a_{nn}
\end{vmatrix} \quad \text{or} \quad D(a_{1n})$$

be the given determinant, and

$$\begin{vmatrix}
a_{pp} & \cdots & a_{pq} \\
\cdots & \cdots & \cdots \\
a_{qp} & \cdots & a_{qq}
\end{vmatrix} \quad \text{or} \quad \delta$$

the chosen minor.

From the elements of $D(a_{1n})$ we form a determinant

$$\begin{vmatrix}
a_{11} & a_{12} & a_{13} & \cdots & a_{1p} & \cdots & a_{1q} & 0 & \cdots & 0 & \cdots & a_{1n} \\
a_{21} & a_{22} & a_{23} & \cdots & a_{2p} & \cdots & a_{2q} & 0 & \cdots & 0 & \cdots & a_{2n} \\
a_{31} & a_{32} & a_{33} & \cdots & a_{3p} & \cdots & a_{3q} & 0 & \cdots & 0 & \cdots & a_{3n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{p1} & a_{p2} & a_{p3} & \cdots & a_{pp} & \cdots & a_{pq} & 0 & \cdots & 0 & \cdots & a_{pn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{q1} & a_{q2} & a_{q3} & \cdots & a_{qp} & \cdots & a_{qq} & 0 & \cdots & 0 & \cdots & a_{qn} \\
a_{p1} & a_{p2} & a_{p3} & \cdots & 0 & \cdots & 0 & a_{pp} & \cdots & a_{pq} & \cdots & a_{pn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{q1} & a_{q2} & a_{q3} & \cdots & 0 & \cdots & 0 & a_{qp} & \cdots & a_{qq} & \cdots & a_{qn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{n1} & a_{n2} & a_{n3} & \cdots & 0 & \cdots & 0 & a_{np} & \cdots & a_{nq} & \cdots & a_{nn}
\end{vmatrix} \quad \text{or} \quad \Delta$$

which is of the $(n+q-p+1)^{\text{th}}$ degree, its rows from the 1^{st} to the q^{th} inclusive being the same as those from the 1st to the q^{th} in the given determinant, except that $q-p+1$ zeros are inserted after the q^{th} element in each, and those from the $(q+1)^{\text{th}}$ to the last inclusive being the same as those from the p^{th} to the last in the original determinant, except that $q-p+1$ zeros are inserted before the p^{th} element in each. Of this determinant the selected minor δ occurs twice as a minor, having zero elements below it in the one case and zero elements above it in the other. Hence, if we take the first q rows and form every minor of the q^{th} degree preparatory to finding the expansion of Δ as a sum of products of complementary minors, we see that, although the full list of minors would be exactly the same as if we had been dealing with $\mathrm{D}(a_{1n})$ instead of Δ, still we need only take those which include the selected minor δ, because all the others have here complementaries which vanish; also we see that the complementaries of those thus taken are not of the degree $n-q$ as in $\mathrm{D}(a_{1n})$, but of the degree $n-p+1$, each one including, in fact, the corresponding complementary in $\mathrm{D}(a_{1n})$ and the selected minor besides. Now it is evident that the sum of products thus found as the equivalent of Δ is exactly the sum of products referred to in the theorem, the addition of $q-p+1$ in the determination of the sign of a product being due to the $q-p+1$ zeros which are inserted in Δ, and which for certain elements make the number of their column greater by $q-p+1$. It thus remains to show that

$$\Delta = \mathrm{D}(a_{1n}) \times \delta\,.$$

Adding each element of the $(q+1)^{\text{th}}$ column to the corresponding element of the p^{th} column, each element of the $(q+2)^{\text{th}}$ column to the corresponding element of the $(p+1)^{\text{th}}$, and so on, as far as the zeros continue, we have

$$\Delta = \begin{vmatrix}
a_{11} & a_{12} & a_{13} & \cdots & a_{1p} & \cdots & a_{1q} & 0 & \cdots & 0 & \cdots & a_{1n} \\
a_{21} & a_{22} & a_{23} & \cdots & a_{2p} & \cdots & a_{2q} & 0 & \cdots & 0 & \cdots & a_{2n} \\
a_{31} & a_{32} & a_{33} & \cdots & a_{3p} & \cdots & a_{3q} & 0 & \cdots & 0 & \cdots & a_{3n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{p1} & a_{p2} & a_{p3} & \cdots & a_{pp} & \cdots & a_{pq} & 0 & \cdots & 0 & \cdots & a_{pn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{q1} & a_{q2} & a_{q3} & \cdots & a_{qp} & \cdots & a_{qq} & 0 & \cdots & 0 & \cdots & a_{qn} \\
a_{p1} & a_{p2} & a_{p3} & \cdots & a_{pp} & \cdots & a_{pq} & a_{pp} & \cdots & a_{pq} & \cdots & a_{pn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{q1} & a_{q2} & a_{q3} & \cdots & a_{qp} & \cdots & a_{qq} & a_{qp} & \cdots & a_{qq} & \cdots & a_{qn} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
a_{n1} & a_{n2} & a_{n3} & \cdots & a_{np} & \cdots & a_{nq} & a_{np} & \cdots & a_{nq} & \cdots & a_{nn}
\end{vmatrix}$$

Now, in this determinant, subtracting each element of the p^{th} row from the corresponding element of the $(q+1)^{\text{th}}$ row, each element of the $(p+1)^{\text{th}}$ row from the corresponding element of the $(q+2)^{\text{th}}$ row, and so on until the elements of the q^{th} row have been reached and subtracted, we have

$$\Delta = \left|\begin{array}{cccccccccccc}
a_{11} & a_{12} & a_{13} & \ldots & a_{1p} & \ldots & a_{1q} & 0 & \ldots & 0 & \ldots & a_{1n} \\
a_{21} & a_{22} & a_{23} & \ldots & a_{2p} & \ldots & a_{2q} & 0 & \ldots & 0 & \ldots & a_{2n} \\
a_{31} & a_{32} & a_{33} & \ldots & a_{3p} & \ldots & a_{3q} & 0 & \ldots & 0 & \ldots & a_{3n} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
a_{p1} & a_{p2} & a_{p3} & \ldots & a_{pp} & \ldots & a_{pq} & 0 & \ldots & 0 & \ldots & a_{pn} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
a_{q1} & a_{q2} & a_{q3} & \ldots & a_{qp} & \ldots & a_{qq} & 0 & \ldots & 0 & \ldots & a_{qn} \\
0 & 0 & 0 & \ldots & 0 & \ldots & 0 & a_{pp} & \ldots & a_{pq} & \ldots & 0 \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
0 & 0 & 0 & \ldots & 0 & \ldots & 0 & a_{qp} & \ldots & a_{qq} & \ldots & 0 \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
a_{n1} & a_{n2} & a_{n3} & \ldots & a_{np} & \ldots & a_{nq} & a_{np} & \ldots & a_{nq} & \ldots & a_{nn}
\end{array}\right|$$

But here there is a set of $q-p+1$ rows having only one non-zero minor of the $(q-p+1)^{\text{th}}$ degree, and this minor being δ and its complementary $\mathrm{D}(a_{1n})$ we have

$$\Delta = \delta\,\mathrm{D}(a_{1n}),$$

the sign of the product $\delta\mathrm{D}(a_{1n})$ being positive, because the numbers of the rows in which the elements of δ occur are the same as the numbers of the columns, and the sum of the two sets of numbers therefore even. This identity is what remained to be proved, hence the theorem is established.

In the introductory example all the rows but two were overlapped, the chosen minor of $\mathrm{D}(a_{15})$ being thus of the third order. The other possible cases for the same determinant are (2) where the chosen minor is of the second order, say $|\,a_{33}\,a_{44}\,|$, and then we have

$$|a_{33}a_{44}|\mathrm{D}(a_{15}) = |a_{11}a_{22}a_{33}a_{44}|\,|a_{33}a_{44}a_{55}| - |a_{11}a_{23}a_{34}a_{45}|\,|a_{32}a_{43}a_{54}| + |a_{12}a_{23}a_{34}a_{45}|\,|a_{31}a_{43}a_{54}|$$

(3) where the chosen minor is of the first order, a_{33} say, in which case we have *two* identities, viz.,

$$\begin{aligned} a_{33}\mathrm{D}(a_{15}) = {} & |\,a_{11}a_{22}a_{33}\,|\,|\,a_{33}a_{44}a_{55}\,| - |\,a_{11}a_{23}a_{34}\,|\,|\,a_{32}a_{43}a_{55}\,| + |\,a_{11}a_{23}a_{25}\,|\,|\,a_{32}a_{43}a_{54}\,| \\ & + |\,a_{12}a_{23}a_{34}\,|\,|\,a_{31}a_{43}a_{55}\,| - |\,a_{12}a_{23}a_{35}\,|\,|\,a_{31}a_{43}a_{54}\,| + |\,a_{13}a_{24}a_{35}\,|\,|\,a_{31}a_{42}a_{53}\,|, \end{aligned}$$

and

$$\begin{aligned} a_{33}\mathrm{D}(a_{15}) = {} & |\,a_{21}a_{33}\,|\,|\,a_{32}a_{43}a_{54}a_{15}\,| - |\,a_{22}a_{33}\,|\,|\,a_{31}a_{43}a_{54}a_{15}\,| + |\,a_{23}a_{34}\,|\,|\,a_{31}a_{42}a_{53}a_{15}\,| \\ & - |\,a_{23}a_{35}\,|\,|\,a_{31}a_{42}a_{53}a_{14}\,|. \end{aligned}$$

If the excess of the number indicating the order of the original determinant over that indicating the order of a minor of it be E, it is readily seen that the number of possible expansions thus obtainable for the product of the determinant and its minor is the highest integer in $\frac{1}{2}$ E.

2. REDUCTION OF THE ORDER OF A DETERMINANT.—Taking the determinant

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} & \ldots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \ldots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \ldots & a_{3n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & a_{n3} & \ldots & a_{nn} \end{vmatrix} \quad \text{or } \mathrm{D}(a_{1n}),$$

and multiplying each element of the first column by $-a_{12}$ and adding to the result a_{11} times the corresponding element of the second column, we have

$$-a_{12}\mathrm{D}(a_{1n}) = \begin{vmatrix} 0 & a_{12} & a_{13} & \ldots & a_{1n} \\ |a_{11}\, a_{22}| & a_{22} & a_{23} & \ldots & a_{2n} \\ |a_{11}\, a_{32}| & a_{32} & a_{33} & \ldots & a_{3n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ |a_{11}\, a_{n2}| & a_{n2} & a_{n3} & \ldots & a_{nn} \end{vmatrix}$$

Similar operations lead finally to

$$(-1)^{n-1}a_{12}\, a_{13} \ldots a_{1n}\, \mathrm{D}(a_{1n}) = \begin{vmatrix} 0 & 0 & \ldots & 0 & a_{1n} \\ |a_{11}\, a_{22}| & |a_{12}\, a_{23}| & \ldots & |a_{1n-1}\, a_{2n}| & a_{2n} \\ |a_{11}\, a_{32}| & |a_{12}\, a_{33}| & \ldots & |a_{1n-1}\, a_{3n}| & a_{3n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ |a_{11}\, a_{n2}| & |a_{12}\, a_{n3}| & \ldots & |a_{1n-1}\, a_{nn}| & a_{nn} \end{vmatrix}$$

Hence, dividing by $(-1)^{n-1}a_{12}\, a_{13} \ldots a_{1n}$, we have

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} & \ldots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \ldots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \ldots & a_{3n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & a_{n3} & \ldots & a_{nn} \end{vmatrix} = \frac{1}{a_{12}\, a_{13} \ldots a_{1n-1}} \begin{vmatrix} |a_{11}\, a_{22}| & |a_{12}\, a_{23}| & \ldots & |a_{1n-1}\, a_{2n}| \\ |a_{11}\, a_{32}| & |a_{12}\, a_{33}| & \ldots & |a_{1n-1}\, a_{3n}| \\ \ldots & \ldots & \ldots & \ldots \\ |a_{11}\, a_{n2}| & |a_{12}\, a_{n3}| & \ldots & |a_{1n-1}\, a_{nn}| \end{vmatrix} \quad \ldots (\mathrm{A}_1)$$

the second determinant being of the $(n-1)^{\text{th}}$ order.

This identity has been long known: it is proved in BRIOSCHI by means of the multiplication theorem. But now applying to the determinant of reduced order the theorem by which it itself was obtained, and putting

$$\begin{vmatrix} |a_{11}\ a_{22}| & |a_{12}\ a_{23}| \\ |a_{11}\ a_{32}| & |a_{12}\ a_{33}| \end{vmatrix} = a_{12}\,|a_{11}\ a_{22}\ a_{33}|\,,$$

$$\begin{vmatrix} |a_{12}\ a_{23}| & |a_{13}\ a_{24}| \\ |a_{12}\ a_{33}| & |a_{13}\ a_{34}| \end{vmatrix} = a_{13}\,|a_{12}\ a_{23}\ a_{34}|\,,$$

$$\cdots\cdots = \cdots\cdots$$

as the identity in the opening paragraph entitles us to do, we find

$$D(a_{1n}) = \frac{1}{a_{12}a_{13}\ldots a_{1n-1}} \cdot \frac{1}{|a_{12}a_{23}|\ |a_{13}a_{24}| \ldots |a_{1n-2}a_{2n-1}|} \begin{vmatrix} a_{12}|a_{11}a_{22}a_{33}| & a_{13}|a_{12}a_{23}a_{34}| & \ldots \\ a_{12}|a_{11}a_{22}a_{43}| & a_{13}|a_{12}a_{23}a_{44}| & \ldots \\ \ldots & \ldots & \ldots \\ a_{12}|a_{11}a_{22}a_{n3}| & a_{13}|a_{12}a_{23}a_{n4}| & \ldots \end{vmatrix}$$

and therefore

$$D(a_{1n}) = \frac{1}{|a_{12}\ a_{23}|\ |a_{13}\ a_{24}| \ldots |a_{1n-2}\ a_{2n-1}|} \begin{vmatrix} |a_{11}\ a_{22}\ a_{33}| & |a_{12}\ a_{23}\ a_{34}| & \ldots & |a_{1n-2}\ a_{2n-1}\ a_{3n}| \\ |a_{11}\ a_{22}\ a_{43}| & |a_{12}\ a_{23}\ a_{44}| & \ldots & |a_{1n-2}\ a_{2n-1}\ a_{4n}| \\ \ldots & \ldots & \ldots & \ldots \\ |a_{11}\ a_{22}\ a_{n3}| & |a_{12}\ a_{23}\ a_{n4}| & \ldots & |a_{1n-2}\ a_{2n-1}\ a_{nn}| \end{vmatrix} \ldots (A_2)$$

In exactly similar fashion we can next show that

$$D(a_{1n}) = \frac{1}{|a_{12}\ a_{23}\ a_{34}| \ldots |a_{1n-3}\ a_{2n-2}\ a_{3n-1}|} \begin{vmatrix} |a_{11}\ a_{22}\ a_{33}\ a_{44}| & \ldots & |a_{1n-3}\ a_{2n-2}\ a_{3n-1}\ a_{4n}| \\ |a_{11}\ a_{22}\ a_{33}\ a_{54}| & \ldots & |a_{1n-3}\ a_{2n-2}\ a_{3n-1}\ a_{5n}| \\ \ldots & \ldots & \ldots \\ |a_{11}\ a_{22}\ a_{33}\ a_{n4}| & \ldots & |a_{1n-3}\ a_{2n-2}\ a_{3n-1}\ a_{nn}| \end{vmatrix} \ldots (A_3)$$

and so on, the extreme case being, as it is curious to note, the extreme case also of the theorem of § 1., viz., that exemplified by (α).

(A_1) is practically useful in evaluating a determinant whose elements are given in figures. It suggests, however, another identity closely resembling it and established in the same way, viz.,

$$\begin{vmatrix} a_{11} & a_{22} & a_{13} & \ldots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \ldots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \ldots & a_{3n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & a_{n3} & \ldots & a_{nn} \end{vmatrix} = \begin{vmatrix} |a_{11}\ a_{22}| & |a_{11}\ a_{23}| & \ldots & |a_{11}\ a_{2n}| \\ |a_{11}\ a_{32}| & |a_{11}\ a_{33}| & \ldots & |a_{11}\ a_{3n}| \\ \ldots & \ldots & \ldots & \ldots \\ |a_{11}\ a_{n2}| & |a_{11}\ a_{n3}| & \ldots & |a_{11}\ a_{nn}| \end{vmatrix} \div |a_{11}|^{n-2} \ \ldots (B_1)$$

which is still better adapted for this purpose, more especially if $a_{11}=1$ or a low integer. By the continued application of (B_1) there results a series of identities corresponding to (A_2), (A_3) . . . viz.,

$$D(a_{1n}) = \begin{vmatrix} |a_{11}\,a_{22}\,a_{33}| & |a_{11}\,a_{22}\,a_{34}| & \ldots & |a_{11}\,a_{22}\,a_{3n}| \\ |a_{11}\,a_{22}\,a_{43}| & |a_{11}\,a_{22}\,a_{44}| & \ldots & |a_{11}\,a_{22}\,a_{4n}| \\ \ldots & \ldots & \ldots & \ldots \\ |a_{11}\,a_{22}\,a_{n3}| & |a_{11}\,a_{22}\,a_{n4}| & \ldots & |a_{11}\,a_{22}\,a_{nn}| \end{vmatrix} \div |a_{11}\,a_{22}|^{n-3} \quad . \; . \; . \quad (B_2)$$

$$D(a_{1n}) = \begin{vmatrix} |a_{11}\,a_{22}\,a_{33}\,a_{44}| & \ldots & |a_{11}\,a_{22}\,a_{33}\,a_{4n}| \\ |a_{11}\,a_{22}\,a_{33}\,a_{54}| & \ldots & |a_{11}\,a_{22}\,a_{33}\,a_{5n}| \\ \ldots & \ldots & \ldots \\ |a_{11}\,a_{22}\,a_{33}\,a_{n4}| & \ldots & |a_{11}\,a_{22}\,a_{33}\,a_{nn}| \end{vmatrix} \div |a_{11}a_{22}a_{33}|^{n-4} \quad . \; . \; . \quad (B_3)$$

and so on.

§ 3. PRODUCT OF A DETERMINANT AND A POLYNOMIAL.—*The product of a determinant of the* n*th* *order by an expression of* n *terms is equal to the sum of* n *determinants, the first of which is got from the given determinant by multiplying each element of the first row by the corresponding term of the given expression; the second by multiplying similarly each element of the second row, the third by multiplying similarly each element of the third row, and so on.*

Let the given determinant be

$$|a_{11}a_{22}a_{33} \; . \; . \; . \; a_{nn}| \text{ or } D(a_{1n}),$$

and the given expression

$$\xi_1 + \xi_2 + \xi_3 + \; . \; . \; . \; + \xi_n \, ,$$

then the n determinants referred to are

$$\begin{vmatrix} \xi_1 a_{11} & \xi_2 a_{12} & \ldots & \xi_n a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & \ldots & a_{nn} \end{vmatrix} , \quad \begin{vmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ \xi_1 a_{21} & \xi_2 a_{22} & \ldots & \xi_n a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{2n} & \ldots & a_{nn} \end{vmatrix} , \; . \; .$$

Now the coefficient of ξ_1 in the first of them is evidently $a_{11}A_{11}$, in the second $a_{21}A_{21}$, and the third $a_{31}A_{31}$, and so on: therefore in the sum of the n determinants the coefficient of ξ_1 is

$$a_{11}\,A_{11} + a_{21}\,A_{21} + a_{31}\,A_{31} + \; . \; . \; . \; + a_{n1}\,A_{n1} \qquad \text{or} \qquad D(a_{1n})$$

Similarly the coefficient of ξ_2 is seen to be

$$a_{12}\,A_{12} + a_{22}\,A_{22} + a_{32}\,A_{32} + \; . \; . \; . \; + a_{n2}\,A_{n2} \qquad \text{or} \qquad D(a_{1n})$$

and so on. Hence the sum of the n determinants is

$$(\xi_1+\xi_2+\xi_3+\ \ .\ .\ .\ \ +\xi_n)\ \mathrm{D}(a_{1n})$$

as was to be shown.

From this simple theorem there follows at once Mr MALET's theorem* regarding the multiplication of

$$\left|\begin{array}{cccc} 1 & 1 & 1 & 1 \\ \alpha^m & \beta^m & \gamma^m & \delta^m \\ \alpha^n & \beta^n & \gamma^n & \delta^n \\ \alpha^p & \beta^p & \gamma^p & \delta^p \end{array}\right| \quad \text{or } \mathrm{F}(\ \ m, n, p)$$

by $\alpha+\beta+\gamma+\delta$, the product in question evidently being

$$\mathrm{F}(1\ \ m, n, p) + \mathrm{F}(0, m+1, n, p) + \mathrm{F}(0, m, n+1, p) + \mathrm{F}(0, m, n, p+1)\ ;$$

and the theorem is seen to be capable of extension not merely as regards the order of the determinant (as Mr MALET indicated), but as regards also the degree of the multiplier, which, instead of being $\Sigma\alpha$, might as easily be $\Sigma\alpha^r$.

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* "Educational Times" Reprint, vol. xxviii. p. 51.

III.—*Chapters on the Mineralogy of Scotland. Chapter Sixth.— "Chloritic Minerals."* By Professor HEDDLE.

(Read 3d March 1879.)

"CHLORITIC MINERALS."

There is no department of natural science which is so defective in its general scheme of arrangement as mineralogy; and its sectional grouping is, if possible, still more defective.

Such correlations as are expressed by the terms, "the Micas,"—"the Felspars,"—"the Garnets," &c., are only admissible if the substances united in such groups are included under one general formula, and function in a more or less similar manner as rock-formers.

Under such methods of arrangement as are in vogue, many substances are left to stand isolated as intermediates,—substances which frequently form important integers of a regular sequence. And when such groups are constituted upon the possession of merely some one general feature, it almost invariably results that there are linked together substances which have nothing else in common.

Mineralogy presents numberless examples of the misleading effect of being guided by mere externals; and the more the *geognostic relations* of minerals are sought out, the more clearly do we see the false conclusions into which we are drawn when we are guided by externals alone.

To no group does this perhaps apply more emphatically than to that of the "*Chlorites.*" Of the twelve minerals which in our systems find a place therein, some are the products of mere solution, some of direct chemical change, some of metamorphic transmutation. Of these, some are found in sedimentary rocks, some in volcanics;—in limestone, in serpentine, in schists, in granite, and in traps.

The extreme injudiciousness of founding a natural history group upon so trivial a character as *colour* alone, is shown by the laxity which has gradually crept in—by the expanding as it were of the name into "the chloritic group," or "chloritic minerals."

From the difficulty of discriminating between several substances which fall under such a term, there can be no doubt that the term has not unfrequently been adopted as a convenient cover for ignorance.

"I always say *chloritic mineral* when any of my students ask me what they are; it covers a vast amount of ignorance." This was the remark made to me by a teacher of geology when we were discussing the green substances which plug the steam-holes of amygdaloids:—the deductions to be drawn from the present investigation will show that the term employed, instead of covering, *exposed* that which it was intended to conceal.

From the very frequent occurrence of difficultly-recognisable green minerals in volcanic rocks, it is to them that this term of "chloritic" is now *specially* applied; it is so applied in the belief and hope that the mineral is a chlorite of some kind, and this is conceived to be quite a sufficient amount of knowledge.

In proof that the case has, in the above, neither been misstated nor overstated, I beg to refer to a paper, entitled "Notes on the Occurrence of Chlorite among the Lower Silurian Volcanic Rocks of the English Lake District," which was lately published in the "Mineralogical Magazine," by Mr J. CLIFTON WARD, of Her Majesty's Geological Survey.

In this paper, which is a record of much careful observation, Mr WARD very seldom uses the term chloritic mineral, and commits himself to the substance being chlorite itself. In this belief he is so confident that he states that the chlorite can be seen to pass into magnesian mica, and even into potash mica; he discusses the nature, or rather the stages of the metamorphism which accomplishes this change; and yet the paper not only does not state that any steps were taken to determine the actual nature of the substance treated of in this important speculation, but it bears internal evidence that neither analysis or any satisfactory test had been adopted for the determination.

In this memoir the mineral in question is directly referred to upwards of thirty times, and indirectly several times more; and yet, *if the evidence of Scotch rocks is not in absolute discordance with those of the English rocks*, I am able to say that, while at three of the localities mentioned,* it is possible that the mineral may be chlorite, in all the rest it is certainly a substance which has no connection therewith.

It is not meant to be insisted on that true metamorphism may not take place in volcanic rocks; but a study of Mr WARD's admirably precise descriptions goes to show that *degradation*, or at least not metamorphism pure and simple, had altered the rocks he treats of—had filled their vesicles, and lined their nests. And, while decomposition and recomposition through degradation is not insisted on as the sole *possible* change, it has to be said that it is the only one which has as yet been clearly shown to alter such rocks.

But Mr WARD's position, as he himself shows, is precisely that of the first petrologists of the day. He writes:—"Under the head of Diabase, ZIRKEL

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* Great Gable, Eskdale, and Harter Fell. The fan-shaped crystalline groups of Harter Fell are very probably chlorite. The nests from the same locality, ranging up to 1 inch in diameter, composed of a "fibrous crystalline" mineral, can hardly be so. As these large nests, a single one of which would suffice for an analysis, can, with "a little careful hammering, be taken out whole from the rock," it is much to be regretted that they were not examined; as a *fibrous* crystalline green mineral would in all probability prove to be either Kirwanite, or new.

remarks ('Microskopische Beschaffenheit,' p. 407), that the diffused greenish mineral seems to be chlorite, and probably a decomposition product of augite, and the same is very likely the case among the Cumberland rocks, for the larger augite crystals, which occur in considerable abundance among some of the lava-flows, are often replaced by," &c. Now, here surely is evidence of *a sufficiency* being obtainable for analysis. The eye can be educated to such a use of the microscope as to be able to trace a gradual process of decomposition, but never to determine the composition of an unknown mineral.

COTTA also is in much the same position. In defining diabase, and enumerating its components, he says, "and some chlorite." "The green colour of the rock is chiefly owing to its chlorite." "The most marked feature of its difference from dolerite is its chlorite, and its consequent green colour. If this chlorite be a product of transmutation, then all the original difference between diabase and dolerite probably consists in the level or depth of solidification."

It is significant that COTTA does not enumerate chlorite among the minerals accessory to diabase in its clefts and veins; while he says, "The vesicular cavities are filled with . . . . . chlorite, glauconite, ... and the like." It is well known that the veins of a rock contain the materials of its general structure in giant-development of crystals, while its amygdules and druses contain the products of the transmutation thereof, through aqueous change and transfer.

Lately, however, clearer light is beginning to be thrown on the matter, for we have DANA supporting ROSENBUSCH when he says that chlorite is not an essential characteristic of diabase; and those who look in Scotland for chlorite in rocks in all other respects entitled to the name of diabase will certainly find none.

If we are to accept and found upon the above admissions—namely, that the amygdules of these so-called chloritiferous-volcanics contain the material which, diffused in minute granular or flaky condition throughout their mass, imparts the occasional green tint, then my analyses have determined that material to be in no way connected with chlorite except in colour.

The results of the following investigation go to show that the minerals usually thrown together under the term which I somewhat unwillingly adopted as the heading of this chapter, are to be grouped under two absolutely distinct heads. For the first the old term of *the chlorites* may be retained; to the second the term *the saponites* may be applied, from the unctuous feeling which is a marked characteristic of them all.

So far as the evidence of over fifty analyses and much contingent observation entitles me to speak, the members of the first of these groups are found only in sedimentary and metamorphic rocks, never occurring in volcanics; the second are confined invariably to the latter, never being seen in the former class of rocks.

The members of first are not decomposed by chlorhydric acid, and there is no peculiarity in the manner in which their constituent water functions.

The members of second are (with one exception) readily decomposed by chlorhydric acid, and the mode in which a portion of their constituent water is held in combination is anomalous.

The first are to be regarded as constituents of the rock mass which contains them,—paragenetic in time with the minerals associated with them.

The second are products of the degradation of the primal constituents of the rock, and are compounds of a more stable nature than the originals which yielded them through a destructive change.

It has to be admitted that the minute granular or crypto-crystalline nature of certain of these minerals renders them extremely difficult of discrimination, but the above may safely be used as leading-lines for the separation of the two classes, and the distinctions which will enable us in future to identify the individual members will be noticed after the consideration of the whole.

So far as I have yet ascertained, the following members of each of these groups occur in this country :—

Chlorites.

Glauconite.
Talc-chlorite.
Penninite.
Ripidolite.
Chlorite.
Chloritoid.

Saponites.

Delessite.
Chlorophæite.
Hullite.
Saponite.
Celadonite.

THE CHLORITES.

Many of the denser "chloritic minerals" are so crypto-crystalline in their structure that we can call in the aid of neither the goniometer nor the polariscope in their determination ; we are thus confined for the most part to physical and chemical characters. Sooth to say, the first of these lend hardly any aid, if they do not even somewhat tend to confuse.

As thus: Taking Dana as usual as our English guide, we find the following ranges of specific gravities

	from	to
Of Penninite	2·6	2·85
Leuchtenbergite,	2·61	2·71
Ripidolite,	2·65	2·78
Chlorite,	2·78	2·96
Pyrosclerite,	2·74	
Epichlorite,	2·76	
Delessite,	2·89	
Strigovite,	3·144	
Thuringite,	3·151	3·197

From out of these, no one of which in their fine-grained or ill-defined forms can easily be distinguished from the others, only the two last can be selected as standing in any measure apart.

But even as regards the three commoner species, I cannot say that the evidence of such specimens, as analysis indicates to me should be placed under each of these species, bears out the ranges of specific gravity as limited by Dana.

In allocating them by constitution alone we have little difficulty as regards true chlorite. Its low content of silica, and to a certain extent its lower magnesia and water, and its high alumina and ferrous oxide, enable us clearly to draw the line between it and the others.

But the larger amount of alumina in ripidolite is the sole feature of distinction between that mineral and penninite.

Allocating the varieties I have analysed in accordance with these lines, I find the specific gravities to have the following ranges:—

	from	to
Of Penninite,	2·59	3·099
Ripidolite,	2·823	2·959
Chlorite,	2·697	3·038

Supposing my allocation to be correct, this shows that the three species do not differ in gravity.

Searching for aid from geognostic relationships we find little or none, and are again brought painfully in face of one of the shortcomings of mineralogical works, a shortcoming which I have already alluded to in speaking of the micas,—namely, the dearth of information accorded to us by them, relating to the special rocks in which minerals are found, and also as to the other mineral species which are associated with them.

Even the ponderous and classical work of DANA tells us no more than the following :—

> Penninite, " with serpentine ;"
> Ripidolite, " in connection with chlorite and talcose rocks in schists and serpentine ;"
> Chlorite, " same as for ripidolite."

There is certainly no geognostic distinction in this, and the evidence of the specimens analysed by me, so far from importing more precision, has an opposite effect; for, while it widens the geognostic scope of the occurrence of these minerals, it does so at the cost of opening up the habitats very much to each and all.

I speak only from evidence drawn from specimens actually analysed, and the record runs thus :—

Penninite,—serpentinous belt in hornblendic gneiss ; ditto in mica slate ; in serpentine ; *pseudophite* in uralitic diorite.

Ripidolite, in actynolitic belt in hornblendic gneiss ; in steatitic belts in chlorite slate ; in granular limestone in mica slate.

Chlorite, in serpentinous belt in mica slate ; in intrusive granite ; in quartzose belts in mica slate ; in granular limestone ; in mica slate and gneiss.

Were we to lay weight upon numerical evidence, or frequency of occurrence in each rock, we should have to make the record more confusing still, by saying that chlorite most frequently affects granular limestones and quartzose belts ; while penninite and ripidolite affect " chloritic rocks."

Premising then in these general remarks that the fine-grained varieties are arranged in virtue of their chemical features, I now give the analyses of each, considering the three more important species first.

Arranged in the order of their content of silica, they stand as on page 58.

PENNINITE.

From Serpentine in Hornblendic Gneiss.

1. From the island of Scalpa or Glass, near Harris.

A small promontory and a short stretch of the adjoining eastern coast of this island consists of a bed of serpentine ; this is regularly interstratified with the gneiss, which dips to the south-east. The serpentine along the coast is very inaccessible, on account of its extending but little inland from a line of precipitous cliffs. The small protruding point was many years ago chosen as the site of a lighthouse. The works connected with the cutting a foundation platform, and the building of a pier exposed the stratum, and showed its relations to the gneiss. This spot acquired some interest shortly after the building of the lighthouse, on account of the mineral zircon having been first here found in the British Islands by Patrick Neill in 1811. The crystals of zircon, which are very minute, lie imbedded in the mineral analysed. This constitutes a bed of about a couple of feet in thickness; its colour is a very dark green; the larger bed is divided into smaller, differing somewhat in structure. The general mass which contains the zircon crystals is hard, somewhat coarse and slaty; it carries veins of steatite, Dolomite, and thinner portions of chlorite itself, of a structure which is softer, minute-granular, or even scaly. The scales, however, are so minute that they are hardly recognisable, and this closeness of structure has led to its having been called potstone; at least potstone has been said here to occur, and this is the only substance which I found at the locality likely to have been mistaken for it.

The specific gravity of this finer-grained and purer variety is 3·099.

1·628 grammes yielded—

Silica,	·465		
From Alumina,	·036		
	·501	=	30·405
Alumina,			11·58
Ferric Oxide,			2·343
Ferrous Oxide,			10·71
Manganous Oxide,			1·19
Lime,			trace
Magnesia,			30·634
Potash,			·01
Soda,			1·306
Water,			11·743
			99·921

1·3 per cent. of the silica were insoluble. It possibly contained a very minute quantity of magnetite, as crystals of this were seen in other specimens.

2. From half a mile south of the farm of Corrycharmaig in Glen Lochy, Perthshire.

The rock of the district is a mica-schist, with veins of a peculiar claret-coloured hyaline quartz carrying chlorite and rutile.

At the locality whence the mineral was taken, chromite had been wrought.

It occurred in a highly tortuous vein, which, with its veinstone, was about six feet wide. This vein runs in a general sense along the strike.

A considerable quantity of penninite lay about the old workings, but pure pieces were rare ; it was also associated with picrolite and "baltimorite."

The first specimen I saw I obtained from the dealer DORAN, who sold it as Leuchtenbergite: this differed from any specimen I have seen either on the spot or elsewhere in Scotland. It consisted of a band or layer of foliated crystals of half an inch or more in thickness, said crystals lying transverse to the sides of the layer. Its colour was leek green. The specimens I obtained on the spot were of a dark-green colour: they all consisted of masses of foliaceous crystals of half an inch in size, but these all lay in parallel arrangement with the rock matrix. Their lustre was high, and not pearly. Specific gravity, 2·895.

1·542 grammes yielded—

Silica,	·505	
From Alumina,	·024	
	·529 =	34·306
Alumina,		13·64
Chromium Sesquioxide,		trace
Ferric Oxide,		·364
Ferrous Oxide,		10·305
Manganous Oxide,		·227
Lime,		8·97
Magnesia,		18·041
Potash,		1·36
Soda,		·13
Water,		12·407
		99·75

Insoluble silica, 6·79. Was apparently quite pure.

3. *Kammererite.*—This chromiferous variety I first found in Britain in the year 1848. It occurred in a granular massive form in considerable quantity in the great quarry of chromite at Hagdale in Unst, Shetland. Its colour is purple to bluish purple. It ordinarily contains nodules of the size of shot, which are quite granular, and probably differ in composition. These were removed. Rarely it is foliaceous, and still more rarely regular imbedded hexagonal crystals are to be seen; these are less than a quarter of an inch in size. They are pale violet in colour, and sometimes light green. They are readily cleavable into thin foliæ.

Of the massive variety, which was analysed, the specific gravity is 3·099.

The analysis on 25 grains yielded—

Silica,	29 · 894
Alumina,	12 · 931
Chromium Sesquioxide,	5 · 967
Ferrous Oxide,	1 · 955
Nickel Oxide,	trace
Lime,	3 · 54
Magnesia,	29 · 933
Potash,	1 · 156
Soda,	· 974
Water,	13 · 266
Carbonic Acid,	trace
	99 · 616

4. Five and twenty years after the first discovery of this very rare mineral in Unst, it was again obtained by Mr Dudgeon and myself among the vein-stones of a new chromite quarry which lay to the north-west of the House of Buness, some two miles from the original locality. It was here occasionally in fairly well-formed crystals, which are elongated rhombohedra.

The cleavage foliæ of these crystals are optically uniaxial, or with a very slight axial divergence. Their colour is a bright purple. They are over a quarter of an inch in length and breadth.

1 · 3 grammes yielded—

Silica,	· 401	
From Alumina,	· 019	
	· 42 =	32 · 307
Alumina,		7 · 497
Chromium Sesquioxide,		7 · 888
Ferrous Oxide,		2 · 076
Lime,		3 · 833
Magnesia,		32 · 153
Water,		14 · 246
		99 · 90

Insoluble silica, 5 · 233. Was apparently pure.

At both of the above localities of Kammererite it was associated with a pulverulent substance of a light-yellow colour. Analysis showed this substance to be new. I have elsewhere described it under the name of *Hibbertite.*

5. *Pseudophite.*—This allomorph, which I now introduce as new to Britain, was obtained by Professor Nicol and myself from the east side of Beauty Hill, in Aberdeenshire.

It occurred in thin veins in a gabbro, which was composed of apparently a dark granular augite or uralite, the crystals of which, of the size of large shot, were singly imbedded in a waxy-looking massive labradorite,—"Saussurite" (?)

The veins were sharply defined, but the labradorite was seen within an inch or so of the veins to become greenish in colour and *actually to pass by insensible gradation* into the mineral described.

The colour of this substance in the veins was pale sap-green: it was translucent, tough, and like slate-pencil, and had a specific gravity of 2·59. There were no associated minerals.

1·264 grammes yielded—

Silica,	·431		
From Alumina,	·008		
	·439	=	34·731
Alumina,			12·444
Ferrous Oxide,			2·684
Manganous Oxide,			1·17
Lime,			1·595
Magnesia,			34·098
Water,			13·1
			99·822

Insoluble silica, 6·834 per cent. The specimen analysed was perfectly pure.

Since the above analysis was made, my attention has been particularly directed to *pyrosclerite* by Professor KING of Galway, with a view to the correlation of the gneissic limestones of the west of Scotland with those of Connemarra in Ireland.

The Beauty Hill mineral differs from a specimen of pyrosclerite sent to me by Professor KING as from Elba, in the single respect of being somewhat harder, perhaps also in being a little paler in colour. But it is a question if the Elba mineral is truly pyrosclerite.

DANA makes pyrosclerite a micaceous mineral, with eminent cleavages; pseudophite he refers to as compact-massive, and without cleavages; in other physical characters, as well as in chemical composition, they are almost identical; and if, as is held, pyrosclerite occurs in a colloidal state, it is not easy to see how any line can be drawn between the two.

As regards the present mineral, considered in the light of the slight differences which do exist between them in their typical forms, it more agrees with pyrosclerite in hardness,—with pseudophite in gravity and in structure,—while its being apparently an alteration product of a *felspar*, is a feature which has as yet been assigned to neither. As certain of the "colloidal pyrosclerites" sent me by Professor KING, both from St Phillipe in the Vosges, and from Ireland, very much resemble pseudomorphs (set down as serpentine after sahlite), which occurs in the Glenelg limestone, and also thin veins which cut the serpentine of Portsoy (set down as being precious serpentine), I shall, after analysing these, take this question up in treating of the serpentines.

RIPIDOLITE.

From Limestone in Mica Slate.

1. It is probably the continuation of the great bed of limestone which courses down Glen Tilt which crosses the Garry to the south of the village of Blair Athol, and which then curves westward by the Allt Bhaic.

A small quarry of this limestone has been wrought on the south side of the stream, under the slopes of the Hill of Tulloch.

The highly plicated beds of the lime contain scaly masses and rosette crystallisations of ripidolite associated with Biotite and quartz. The ripidolite is pale olive green in colour, and has a pearly lustre.

The rosettes have a hexagonal *arrangement*, but the structure is not sufficiently simple and evident to allow of the form being determined.

1 · 34 grammes yielded—

Silica,	·383		
From Alumina,	·023		
	·406	=	30 · 298
Alumina,			19 · 397
Ferrous Oxide,			8 · 232
Manganous Oxide,			·373
Magnesia,			29 · 104
Water,			13 · 07
			100 · 474

Insoluble silica, 6 · 182 per cent.

A perfectly similar mineral occurs in a limestone quarry north-east of Edintian; this lime is probably the continuation of the Lude bed. The associates here are pyrrhotine, Biotite, sphene, and ilmenite.

From Chlorite Slate.

2. The southern half of the promontory of Hillswickness in the mainland of Shetland is composed of rocks which may be grouped under the above name.

At a point on the south-west shore of that ness, near the prominent Gardie Stack, there is a crevice called Sandy Geo. Stakes of wood are driven into the turf, from which the islanders suspend themselves by ropes while gathering sea-weed from the foot of the cliffs. By the exercise of extreme care, however, ropes may for a certain part of the descent be dispensed with, and a bed of steatite which protrudes from the slippery bank be reached. This bed has —as has another such in Shetland—been applied by the Shetlanders to the singular purpose of serving as a record of pledged vows—the names of the engaging parties being carved, with date attached, into the steatite. Numerous single individuals have, however, by the exercise of their graphic powers, profaned this sanctuary.

The locality is called the Klebber-names,—Klebber being the Norwegian name for steatite.

The greater mass of the steatite here, if it be steatite, is of a purplish-red colour. Disposed throughout it, and perhaps chiefly in those portions which are somewhat green in colour, are numerous isolated rosette crystallisations, nearly spherical in form, and the centre of each sphere is occupied by an octohedral crystal of magnetite.

As the crystals of the magnetite are of sharply and regularly developed form, of a fine blue colour and a high lustre, they contrast well with the ripidolite, the diverging plates of which are smooth, of high transparency, and a beautiful emerald green. There are thus formed specimens of so singular an appearance that the small size of their parts alone prevents their being regarded as among the most striking of Scottish minerals.

The form of the individual crystals of the fan-shaped radiations cannot, from their small size, be determined. Their minuteness also alone prevented investigation of their optical properties, for they were perfectly transparent.

1 · 275 grammes yielded—

Silica,	·41		
From Alumina,	·005		
	·415	=	32·549
Alumina,			13·95
Ferric Oxide,			·972
Ferrous Oxide,			5·275
Manganous Oxide,			·156
Lime,			·79
Magnesia,			32·785
Potash,			·48
Soda,			·062
Water,			13·173
			100·192

Insoluble silica, 4·819 per cent.; loses 1·961 per cent. of water in the bath.

From Hornblendic Gneiss.

3. At the grandly picturesque headland of Cape Wrath,—or more correctly Rath,—the hornblendic gneiss of the west coast differs in its features very considerably from those which it possesses elsewhere, and which may be said to be almost unvarying. The dip here is low, and to the east or east-south-east. It is highly corrugated and folded, and it is rent and shifted and reagglutinated by an anastimosing and mutually intersecting series of granitic veins. Its own granitic belts, instead of assuming as elsewhere much of the character of a set of parallel dykes, with abrupt and sharply-marked surfaces, blend by insensible gradation into the ordinary material of the rock, which is here even somewhat of the nature of granite itself.

It is this greater consistency of the rock as a whole, this more intimate interpenetration and consequent firmer cohesion of its parts, coupled with the altogether unique manner in which its every layer is bound together by granitic cords of unusual toughness—interlaced in such a manner as to defy unravelling—that has enabled it to form so fitting a termination to a kingdom,—so enduring a rampart against even Atlantic billows.

Such are the features of the rock for about a mile to east and south of the lighthouse. Another feature has, however, to be noticed; it is, within the space so included, much less characterised by the presence of particles of hornblende than is usual, being of a pinkish instead of a green cast of colour. This local deficiency of hornblende is, however, more than compensated for at a point about one and a half miles south of the lighthouse, where the strata have gradually increased their dip, and assumed a line of outcrop which is that normal to the rock in the south. Here the beds suddenly become almost alternatingly hornblendic and felspathic; and as the intermediate felspathic bands have frequently yielded to the weather, those which are hornblendic stand erect in repeated sequence, simulating dykes of a dark igneous rock.

Just about the same spot also, in cove-like recesses of the older rock, the horizontal strata of that many-coloured conglomerate which has been assigned to the Cambrian epoch, make their appearance in outlying portions of very circumscribed dimensions.

In the second (in progressing southward) of these coves of the Cambrian Sea,—one which is now sentinelled on the north by a grand development of the black bands of the older rock, and on the south by an equally grand illustration of intrusively anastomosing granite,—my companion, Professor GEIKIE, and I hit upon an interesting mineral locality.

This is situated on the grassy bank, only some few feet below where the conglomerate reposes in horizontal and peacefully rectilinear beds upon the denuded gneiss, which dips from the under surface of these beds almost at right angles thereto.

The first of these erected beds to which interest attaches, carries hydrous anthophyllite, amianthus, and a jasper-like chert; the second, which is some twenty yards to the south, contains a layer of ripidolite in close association with lavender-grey steatite and actynolitic hornblende.

A year after our discovery of this mineral locality, the present writer found two other localities which lie in similar recesses among the rocks some little distance to the south. These contain the ripidolite in much larger quantity, but here its only associate is hornblende.

This ripidolite forms belts in the rock, which consist of a mass of nearly parallel scales, of about the size of peas. They have a greasy lustre, and a blackish-green colour. Specific gravity, 2·823.

1·102 grammes yielded—

Silica,	·331		
From Alumina,	·011		
	342	=	31·034
Alumina,			14·845
Ferric Oxide,			5·73
Ferrous Oxide,			17·417
Manganous Oxide,			·998
Lime,			·355
Magnesia,			17·422
Water,			12·481
			100·292

·802 per cent. of the water were given off in the bath. Was apparently pure; possible impurity, hornblende.

4. *Aphrosiderite.*—I retain for the specimens now to be noticed the name assigned to them by Greg, as their high content of iron entitles them thereto.

They occur in the chlorite-slate of the south-west of Scotland. An analysis probably of this variety from Bute by Varrentrapp is to be found in Greg and Lettsom's "Manual of Mineralogy." It occurs in large masses along with quartz in the scars on the east side of the Bishop's Hill above Dunoon. Here the structure is coarse and loose scaly, and the colour light green. Imbedded in quartz boulders which lie in the mouth of the stream (the Dirty Burn) which descends from these scars, the mineral is found in a brilliant dark-green minute scaly form. It is here associated with wad and pyrite. Its specific gravity is 2·959.

1·381 grammes yielded—

Silica,	·475		
From Alumina,	·014		
	·489	=	35·409
Alumina,			18·081
Ferric Oxide,			·484
Ferrous Oxide,			26·466
Manganous Oxide,			·608
Lime,			1·013
Magnesia,			8·767
Potash,			·977
Soda,			·522
Water,			8·028
			100·355

The silica here is large in amount. In other respects the analysis is similar to that of the aphrosiderite from Bonschener analysed by ERLENMEYER. It is *possible* that in several of these minutely foliated chlorites there may be interstitial quartz, but it is not probable that it would have escaped notice in the grinding in the smooth agate mortar.

CHLORITE.

From Micaceous Gneiss.

1. The first occurrence I notice was in a serpentinous series of beds, which are interstratified with the gneiss of the north point of the Mainland of Shetland; this point is called Fethaland.

At a small bight termed Pundy Geo there is a bed of massive chlorite of a fine colour, which carries large crystals of magnetite. In association with this there is a picrolitic bed. The gneiss here being almost destitute of felspar, has much of the character of mica slate.

The chlorite here is of a very pure appearance: it has a minutely granular structure composed of foliated crystals confusedly matted together. Its colour is bright green. It is so pervaded with crystals of magnetite that a portion sufficiently free therefrom could not be got for the determination of the specific gravity.

1· gramme yielded—

Silica,	·239		
From Alumina,	·004		
	·243	=	24·3
Alumina,			20·858
Ferric Oxide,			3·567
Ferrous Oxide,			16·718
Manganous Oxide,			·55
Lime,			·504
Magnesia,			22·2
Water,			11·547
			100·244

From Mica Slate.

2. The great band of this rock which passes from north-east to south-west through the lower Highlands of Scotland is everywhere characterised by thin rifts and layers of quartz, which presents features which are markedly different in the different districts where the rock occurs; and there are three very characteristic *bands* of quartz which follow its strike, though not without frequent interruptions in the continuity of their course.

The rock itself is not possessed of well-marked features until in traversing westward we reach the neighbourhood of Ben Bhrackie. Here the quartz presents itself in nodules and laminæ; these are much flawed, and they are characterised by having every here and there a disposition to a yellow coloration, which is sometimes very brilliant. The yellow appears sometimes only disposed in spots, in either a milk-white or in a colourless variety. It has much the appearance of staining; but from the coloration appearing frequently in the interior of the stone and not on its surface, it can be no staining from without, even if we admitted that an outside stain could do more than lodge in cracks.

After having collected specimens of this bright yellow quartz from many localities, I have discovered it to be due to the decomposition of crystals of pyrite; these, now converted in greater part into limonite, lie in the centre of the coloured portions.

I have said that this yellow quartz is first seen on the hill of Ben Bhrackie; it re-appears with even a red hue on the ridge to the east of the Hill of Tulloch, and it may be found here and again—notably on Ben Derag in Glen Lyon, Meall Luaidhe, and Meall Ghaordie (Girdy), along the whole ridge as far as the north slopes of Fiarach near Crianlarich, and the col between Ben Yoss and Ben Laoigh (Loy).

Parallel to but north of the belt of yellow quartz, there occurs a more strongly developed snow-white saccharoid variety; but this is also found in quartzose gneiss, as on the east slopes of Carn Aosda and Carn Chrionaidh in Glen Clunie, and the south-east slopes of Ben Uran; it is not in that rock, however, by any means so strongly developed as in the mica slate.

Of its localities in the latter rock, in none is it so strongly developed as in a knoll to the north-east of the summit of Meall Ghaordie; on the south-west side of this knoll it forms layers of nearly a foot in thickness, and of a purity of colour which was quite equal to the snow out of which I once quarried it.

In a nearly parallel arrangement to the above yellow and white belts, but to the south of both, lies the third, which is quite as marked in its peculiar features.

In the most characteristic specimens, such as are found in the gorge of the Loch of Chat, between Meall Garabh and Ben Lawers, at the foot of the cliffs of Craig Cailleach, and in greatest abundance in the Creag Mohr of Glen Lochy, it may be said to present itself as a hyaline *colloidal* cairngorm.

I purposely use the italicised word to give force to the peculiarity of its appearance, which is that of a large mass of gum, being never crystallised, and having a more than ordinary vitreous lustre.

The colour here, in the finest specimens, is somewhat like that of the finer varieties of cairngorm, but it is very much more delicate, being of a pale brown, markedly dashed with an amethystine tint,—it might be almost called a watery claret.

When cut, it forms stones much to be preferred to any of the brown varieties of the cairngorm.

Now, this variety of quartz, in its finest specimens, carries filaments of rutile—*Venus' hair*—and chlorite. When degraded somewhat in colour it still carries chlorite; and when still further degraded almost to a muddy white, when it is still somewhat hyaline, it carries ilmenite.

The range of this variety may be said to commence on the western slopes of Meall Gruaidh (Croy); to be chloritic and rutiliferous to near Crianlarich; to carry ilmenite from Craig Cailleach, Ben More, and the group around the picturesque Cruach Ardran, as far south at least as the slopes of Ben Ima; and to be chloritic from Ben Derag of Glen Lyon, probably nearly to Macrahanish Bay in Kantyre.

From this stretch I obtained specimens fitted for analysis and also for forming cabinet specimens from the following places:—The west slopes of Ben Derag; Craig-an-Lochan; south-west of Meall Ptarmichan; Cruach Ardran; and Ben Laoigh.

I do not, however, know of rich specimens beyond the south-eastern slopes of the Ben Laoigh.*

Of specimens from the above localities I analysed the following:—

2. From the west slopes of Ben Derag of Glen Lyon.—Associated with quartz: colour, grass-green; structure, matted fine crystals, very dense. Specific gravity, 3·002.

On 1·491 grammes—

Silica,	·3645			
From Alumina,	·004			
	·3685	=	24·715	
Alumina,			21·566	21·657
Ferric Oxide,			·615	
Ferrous Oxide,			26·164	27·025
Manganous Oxide,			·47	
Lime,			·45	
Magnesia,			12·86	12·8
Potash,			1·726	
Soda,			·054	
Water,			10·886	
			99·506	

This is an *aphrosiderite.*

3. From beneath the cliffs of Craig-an-Lochan, Perthshire.—Occurs in quartz of a brown colour, as a confused mass of brilliant dark green minute crystals, rarely slightly brown from weathering; associated very rarely with ilmenite and large flat transparent foliæ of chlorite (?) of a lighter green, which are imbedded in quartz in single plates. Specific gravity 2·697.

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* The Old Red Conglomerate at Callendar contains rarely quartz nodules, with chlorite, very similar in appearance to that of Cruach Ardran.

On 1·519 grammes—

Silica,	·363		
From Alumina,	·006		
	·369	=	24·292
Alumina,			21·147
Ferric Oxide,			·101
Ferrous Oxide,			18·739
Manganous Oxide,			·8
Lime,			1·659
Magnesia,			21·033
Potash,			1·286
Soda,			·564
Water,			10·083
			99·704

8·13 per cent. of the silica insoluble.

From Granular Limestone in Mica Slate.

4. The bed of limestone which appears near the house of Lude, running parallel to that of Glen Tilt, contains small imbedded masses of a pale olive-green colour, sometimes slightly browned. The structure is minute scaly, and the scales are so soft that the mineral has been thought to be "potstone." Specific gravity 2·852.

1·4635 grammes yielded—

Silica,	·332		
From Alumina,	·019		
	·351	=	23·922
Alumina,			22·976
Ferric Oxide,			1·106
Ferrous Oxide,			19·54
Manganous Oxide,			·28
Lime,			2·453
Magnesia,			17·259
Water,			11·784
			99·39

5·67 per cent. of the silica was insoluble: possible impurity, lime.

5. In the same quarry, translucent quartz in layers rarely cuts the lime; and this quartz contains chlorite, which differs from the above only in being of a

bright-green colour. It was examined to see if the difference of the matrix affected the composition of the mineral to any marked extent. Its specific gravity also is 2·852.

1·396 grammes yielded—

Silica,	24·66
Alumina,	23·19
Ferric Oxide,	·636
Ferrous Oxide,	20·579
Manganous Oxide,	·29
Lime,	·4
Magnesia,	17·79
Water,	12·119
	99·664

5·56 per cent. of the silica were insoluble.

The same quarry contains bands of a dark, dense, granular rock rather than mineral; this is perhaps entitled to the name of potstone.

6. A bed of limestone is seen on the highway about a mile east of Loch Laggan in Inverness-shire. This contains much very fine granular chlorite, of a grass-green colour. It is here very soft, and has a specific gravity of 2·834. It contains, imbedded in its mass, large plates of brown Biotite.

1·586 grammes gave—

Silica,	26·25
Alumina,	19·22
Ferric Oxide,	1·67
Ferrous Oxide,	16·44
Manganous Oxide,	1·02
Magnesia,	24·35
Water,	11·67
	100·62

Insoluble silica, 2 per cent.; possible impurity, Biotite.

From Chlorite Slate.

7. The stone of which the houses of Portsoy in Banffshire are built is obtained from a quarry of a very calcareous clay slate, situated on the sea-shore a little to the west of the town. Immediately to the east of this, the first rock seen is a chlorite-slate, or rock; this occurs as a high-tilted bed, dipping south-east. It contains fragmentary and angular masses of dense hornblende rock,

imbedded in a most peculiar manner, and occasional nodules and layers of plicated foliæ of chlorite. These are much intermixed with grains of quartz.

The colour of this chlorite is bright green, mixed with plates of a golden yellow; the lustre is high. It is soft and unctuous. The specific gravity of a portion, apparently nearly free from quartz, was 2·792.

25 grains yielded—

Silica, ...	26·71
Alumina, . . .	20·424
Ferric Oxide, . .	3·472
Ferrous Oxide, . .	13·993
Lime, ...	·726
Magnesia, . . .	23·896
Water, ...	11·17
	100·391

The golden colour may be the result of peroxidation.

From intrusive (?) Granite.

8. The gneiss of the Girdleness, in Kincardineshire, is riddled on both sides of the point with tortuous intrusive veins of granite. One of these, cut across in sinking for the foundations of the new breakwater for the Aberdeen harbour, yielded, in small quantities, small crystals of orthoclase, with epidote and small scaly chlorite.

This chlorite is of a dark-green colour and a high lustre; it sheathes the crystals of orthoclase, which are pale red in colour. Decomposed crystals of pyrite are imbedded both in the chlorite and in the orthoclase. The specific gravity of the chlorite is 3·038.

1·304 grammes yielded—

Silica, . . .	·315		
From Alumina, .	·008		
	·323	=	24·769
Alumina, ...			20·164
Ferric Oxide, . . .			1·381
Ferrous Oxide, . .			27·368
Manganous Oxide, . .			·613
Lime, ...			·901
Magnesia, . . .			13·343
Water, ...			12·051
			100·59

Loses 1·453 per cent. of water in the bath.

Chlorite occurs extremely rarely in Scotland in granite. One specimen of a substance which I take to be it was got at Rubislaw.

That the goniometer and polariscope can effect the discrimination of well-crystallised or large-foliated varieties of these three minerals must be admitted; but of the specimens in the succeeding table (p. 80) the following would, after *mere ocular inspection,* be set aside as one and the same.

Scalpay, Bishop's Hill, Fethaland, Ben Derag, Lude, Loch Laggan, and Girdleness; these—which include the *three* species—would be generally regarded as fine-grained massive chlorite.

Craig-an-Lochan, Portsoy, and specimens from Vanlup, Hillswick, and Ben Laoigh, Argyll, would be regarded as large-grained foliated chlorite.

Corrycharmaig, Cape Wrath, and Blair Athol—which include *two* species—would be considered to be all ripidolite.

Again, Bishop's Hill, Ben Derag, and Girdleness, may, as regards the amount of iron, be all regarded as aphrosiderites.

As regards the amount of silica, alumina, and water, those ranked as chlorites seem to stand apart; but, in the other ingredients, the three seem so to run into one another, that the question arises whether one and the same substance be not trimorphic.

The finest rosette crystallisations of chlorite I have found in Scotland occurred at Glen Effoch in Tarffside, in mica schist; on the south-west slopes of Aonach Beg, Inverness-shire; and, along with sphene and fluor in limestone, at "the three burns" south of Gaulrig in Glen Avon. JAMESON mentions its occurrence in fine crystals upon the road from Ardsin to the harbour of the Small Isles in Jura.

CHLORITOID.

1. This mineral is inserted here on account of its name expressing some relation to those first considered, and also from its geognostic relationships being similar. I have also found passages in geological works in which "chloritoidal schists" and "chloritoidal rocks" were referred to, and I quite believe that the name was there employed under the supposition that the word was synonymous with chloritic. It is very probable that the mineral itself was quite unknown to the writers, the present notice being the first occasion on which it has been introduced as a British species.

I obtained it some twenty years ago at Vanlup, Hillswickness, Shetland, imbedded in quartz veins, in close association with kyanite and margarodite. The including rock is a margarodite-schist, generally considered a talc-schist.

The colour of the first specimen found was misleading as regards its nature, being clove or chocolate brown, from a partial peroxidation of its iron.

Its lustre was shining, slightly pearly. Streak greyish. Cleavage basal, perfect, but interrupted; parallel to two lateral planes, imperfect and rough.

Structure foliated. Was in rough lozenge-shaped crystals, which were apparently monoclinic. Brittle.

Hardness, 5·5 on the cleavage plane, 6· on the lateral. Specific gravity, 3·356.

On 1·305 grammes—

Silica,	·302		
From Alumina,	·029		
	·331	=	25·363
Alumina,			41·736
Ferric Oxide,			3·895
Ferrous Oxide,			13·932
Manganous Oxide,			·919
Lime,			·901
Magnesia,			6·82
Water,			6·571
			100·137

Insoluble silica 4·58 per cent.

2. The above analysis having disclosed the nature of the substances which I had regarded as that which had been by some considered Babingtonite, I found upon breaking up masses of the rock that deeper-seated crystals were of a fine dark-green colour; and during a late visit to Shetland, in company with Mr DUDGEON, I refound the mineral, and was thus enabled to examine perfectly unaltered specimens.

These we obtained at the same spot, imbedded in reddish vitreous massive quartz-veins of mica slate, associated with margarodite and pale yellow sphene.

The colour was dark green, the lustre shining and pearly, the streak pale greenish-grey. The specific gravity from 3·313 to 3·462.

24·3 grains yielded—

Silica,	5·746		
From Alumina,	·2		
	5·946	=	24·47
Alumina,			41·336
Ferric Oxide,			·383
Ferrous Oxide,			18·522
Manganous Oxide,			·913
Lime,			·302
Magnesia,			6·8
Water,			6·98
			99·706

Insoluble silica, 3·66 per cent.

TALC-CHLORITE.

The composition of this mineral is expressed, as shown by DANA, by the same general formula as that of pyrosclerite; but a considerable quantity of ferrous oxide here replaces magnesia.

Its specific individuality cannot be said to have been hitherto absolutely determined; it rests upon three closely accordant analyses by MARIGNAC, and an optical determination by DESCLOIZEAUX.

DANA, referring to the excess of its silica above that contained in ripidolite, remarks that "it is possibly ripidolite impure from mixture with talc;" but it is extremely improbable that DESCLOIZEAUX would not have detected such an admixture either while preparing plates for the polariscope, or during the employment of the instrument.

The mineral, I now notice, goes a certain length in aiding in establishing the species.

It was found forming a vein, which occurred on the foreshore, to the south of the Banks of the Nudister, at Hillswick, in Shetland. This vein was associated with a similar one of Biotite. The substance, being damp from recent marine submergence, could be raised in spadefuls. It formed a pulpy and slimy mass of minute glistening scales. These were floated in water to remove adhering salt, and being frequently examined during successive decantations, were seen to be absolutely free from talc, or any impurity.

Their colour was grass-green, with a peculiar bronzy or golden lustre in certain directions. Their lustre was more pearly than that of chlorite or ripidolite. They were exceedingly smooth to the touch.

1 · 3 grammes yielded—

		Marignac.
Silica, ...	39 · 81	39 · 87
Alumina, ...	11 · 432	11 · 91
Ferrous Oxide, . . .	7 · 974	11 · 34
Manganous Oxide, . .	· 259	...
Lime, ...	2 · 804	...
Magnesia, ...	25 · 648	28 · 76
Potash, ...	1 · 203	...
Soda, ...	3 · 152	...
Water, ...	7 · 913	7 · 98
	100 · 194	

The air-dried mineral lost at 212°, 10 · 945 of water in addition to the above; a feature sufficing to distinguish it from either ripidolite or talc.

A "chloritic mineral," differing from this merely in a greater brightness of colour and lustre, occurs a little west of Portsoy.

The average of MARIGNAC's three analyses is appended for comparison.

GLAUCONITE.

1. In company with Dr GORDON of Birnie, Professor NICOL, and Mr DUDGEON, I found this mineral—new to Scotland—in a kind of cornstone quarry at Ashgrove, near Elgin.

It occurs, along with a manganesian calcite and well-crystallised pyrite, acting as an occasional cement of the nodular masses of lime. It is a very soft and friable, somewhat dull-green powder; rarely a bright light-green.

1 · 32 grammes afforded—

Silica,	· 644		
From Alumina,	· 004		
	· 648	=	49 · 09
Alumina,			15 · 206
Ferric Oxide			10 · 565
Ferrous Oxide,			3 · 056
Lime,			· 551
Magnesia.			2 · 651
Potash,			6 · 052
Soda,			1 · 205
Water,			11 · 641
			100 · 017

Loses 6 · 03 of the above water at 212°. It was readily decomposed by acids. Glauconite possibly occurs in some of the silurian limestones of Ayrshire.

	S. G.	$\ddot{Si}$.	$\dddot{Al}_2$.	$\dddot{Fe}_2$.	$\dddot{Cr}_2$.	$\dot{Fe}$.	$\dot{Mn}$.	$\dot{Ca}$.	$\dot{Mg}$.	$\dot{K}_2$.	$\dot{Na}_2$.	$\dot{H}_2$.	Totals.	Matrix.
PENNINITE.														
Scalpay, Harris,	3·099	30·41	11·58	2·34	...	10·71	1·19	tr.	30·63	·01	1·31	11·74	99·92	Serpentine.
Corrycharmaig, G. Lochy,	2·895	34·31	13·64	·36	tr.	10·31	·23	8·97	18·04	1·36	·13	12·41	99·75	Mica slate.
Kammererite—														
Unst, massive,	3·099	29·89	12·93	...	5·97	1·96	...	3·54	29·93	1·16	·97	13·27	99·62	Serpentine.
Do., crystallised,	...	32·31	7·5	...	7·89	2·08	...	3·83	32·15	...	...	14·25	99·9	Do.
Pseudophite, or (?) *Pyrosclerite*—														
Beauty Hill, Aberdeen,	2·59	34·73	12·44	...	...	2·68	1·17	1·6	34·1	...	...	13·1	99·82	Gabbro.
RIPIDOLITE.														
Blair Athol,	...	30·3	19·4	...	...	8·23	·37	...	29·1	...	...	13·07	100·47	Limestone.
Hillswick, Shetland,	...	32·55	13·95	·97	...	5·28	·16	·79	32·78	·48	·06	13·17	100·19	Chlorite slate.
Cape Wrath,	2·823	31·03	14·85	5·73	...	17·42	1·	·36	17·42	...	...	12·48	100·29	Hornblendic gneiss.
Aphrosiderite—														
Bishop's Hill, Argyll,	2·959	35·41	18·08	·48	...	26·47	·61	1·01	8·77	·98	·52	8·03	100·36	Chlorite slate.
CHLORITE.														
Fethaland, Shetland,	...	24·3	20·86	3·57	...	16·72	·55	·5	22·2	...	...	11·55	...	Mica gneiss.
Ben Derag, Perthshire,	3·002	24·72	21·57	·62	...	26·16	·47	·45	12·86	1·73	·05	10·89	99·51	Mica slate.
Craig-an-Lochan, do.	2·697	24·29	21·18	·10	...	18·74	·8	1·66	21·03	1·29	·56	10·08	99·7	Do.
Lude, do.	2·852	23·92	22·98	1·11	...	19·54	·28	2·45	17·26	...	...	11·78	99·39	Limestone.
Do., do.	2·852	24·66	23·19	·64	...	20·58	·29	·4	17·79	...	...	12·12	99·66	Quartz in ditto.
Loch Laggan, Inverness,	2·834	26·25	19·22	1·67	...	16·44	1·02	...	24·35	...	...	11·67	100·62	Limestone.
Portsoy, Banffshire,	2·792	26·71	20·42	3·47	...	13·99	·73	...	23·9	...	...	11·17	100·39	Chlorite slate.
Girdleness, Kincardine,	3·038	24·77	20·16	1·38	...	27·39	·61	·9	13·34	...	...	12·05	100·59	Granite vein.
CHLORITOID.														
Hillswick, green,	3·387	24·47	41·34	·38	...	18·52	·91	·3	6·8	...	...	6·98	99·71	Mica slate.
Do., brown,	3·356	25·36	41·74	3·89	...	13·93	·92	·90	6·82	...	...	6·57	100·41	Do.
TALC-CHLORITE.														
Hillswick,	...	39·81	11·43	...	...	7·97	·26	2·80	25·68	1·2	3·15	7·91	100·19	Chlorite slate.
GLAUCONITE.														
Ashgrove, Elgin,	...	49·09	15·21	10·56	...	3·06	...	·55	2·65	6·05	1·21	11·64	100·02	Cornstone.

THE SAPONITES.

DELESSITE.

From Igneous Rocks of Old Red Sandstone Age.

1. At St Cyrus, north of Montrose, there is a great cliff (a raised beach being between it and the sea) composed of thick beds of conglomerate, with occasional interstrata of amygdaloid. This amygdaloid is studded with agates filling long pipe-shaped steam-holes. These agates are for the most part coated with light-green, translucent, vitreous-lustered celadonite; but the steam-holes themselves are also frequently entirely filled with Delessite.

The structure of the Delessite is scaly,—perfectly recognisable here from the large size of the scales; the colour is sap-green, sometimes passing into red. It is translucent, and scratches easily with the nail.

The specific gravity is 2·652.

The red variety is much of the colour of brick, and seems sometimes pseudo after natrolite; this may be bole (plynthite).

Some specimens of the green variety on being pounded become brownish-red during the progress; this seemed to be partly due to the presence of minute quantities of the red mineral.

Of the pure green 1·3 gramme yielded—

Silica,	·419		
From Alumina,	·006		
	·425	=	32·692
Alumina,			13·435
Ferric Oxide			4·397
Ferrous Oxide,			6·624
Lime,			·861
Magnesia			28·769
Water,			13·245
			100·023

Of the above water, 2·774 *was lost at the temperature of* 212°.

2. In the dense igneous rock above Bowling Quarry, on the Clyde, and between it and Glen Arbuck, this mineral occurs of a close, minutely-foliated structure, and a very dark-green, almost black colour. It is softer than the nail and has a specific gravity of 2·573. Its streak is pale green.

1·3 grammes yielded—

Silica,	·401		
From Alumina,	·015		
	·416	=	32·
Alumina,			17·328
Ferric Oxide,			1·187
Ferrous Oxide,			12·446
Lime,			1·569
Magnesia,			20·423
Water,			15·45
			100·403

Loses 5·7 per cent of water at 212°; insoluble silica, 5·79 per cent.

3. From Dumbuck, on the Clyde.—Occurs in imbedded patches up to the size of beans, in a somewhat decomposing porphyritic trap, a little north of Dumbuck hill. These small masses are frequently irregular in shape, and do not seem as if they had filled cavities which had been pre-existent. The rock contains in association decomposing augite (Ferrite, of WALLACE YOUNG), olivine, and calcite.

The Delessite is of a very dark-green colour, but is markedly lighter in hue when first exposed; it is very soft, has a minutely-foliated structure, and a specific gravity of 2·598.

1·3028 grammes yielded—

Silica,	·398		
From Alumina,	·019		
	·417	=	32·014
Alumina,			18·874
Ferric Oxide,			1·181
Ferrous Oxide,			12·087
Manganous Oxide,			trace
Lime,			1·389
Magnesia,			19·643
Water,			15·456
			100·644

Lost 6·3 of water at 212°; insoluble silica, 8·893 per cent.

4. Occurs in a porphyritic amygdaloid, along with zeolites, at the Long Craig, Dumbartonshire. Colour very dark green, structure massive-granular, rarely glistening. Specific gravity, 2·656.

The first specimen I have from this locality was given to me by the late ALEXANDER BRYSON.

On 1·303 grammes—

Silica,	·399		
From Alumina,	·004		
	·403	=	30·928
Alumina,			15·323
Ferric Oxide,			3·162
Ferrous Oxide,			15·309
Manganous Oxide,			·383
Lime,			1·375
Magnesia,			18·649
Water,			14·692
			99·821

Loses 4·678 of water at 212°; insoluble silica, 2·727 per cent.

From Igneous Rocks intruded among the Coal Measures.

5. About a mile east of the town of Elie, in Fifeshire, two vertical basalt dykes cut tufa.

Small cavities in these dykes are filled with this mineral, which is associated with massive iserine, rarely olivine, and still more rarely fragments of pyrope. Its colour is dark green, it is very minutely scaly, and it is very soft. Its specific gravity is 2·672.

On 1·3 grammes—

Silica,	·391		
From Alumina,	·008		
	·399	=	30·692
Alumina,			12·83
Ferric Oxide,			1·627
Ferrous Oxide,			18·315
Manganous Oxide,			1·
Lime,			1·593
Magnesia,			18·6
Potash,			·567
Soda,			1·112
Water,			13·773
			100·109

Loses 3·389 of water at 212°.

There is every probability that this is the substance mentioned by MACCULLOCH, under the name of chlorophæite, as occurring in Fife.

It is to be observed of all these Delessites that they darken in colour after their first exposure. The water which is given out when heated to 212° is recovered upon mere exposure to an atmosphere in a normal condition as regards its dampness.

There is so much of this mineral exposed upon the surface of the rock about Dumbuck that it cannot, in virtue of the manner in which it functions as regards the nature of the grasp with which it holds part of its water, but affect to a certain extent the state of the atmosphere in the neighbourhood,—moistening it while the sun heats up the rock, and dessicating it in cold weather.

6. There is an alkali-charged variety of this mineral which is found filling small nests in this tufa of Elie Ness near the old Summer-House. This is similar in all external characters to the others, but contains—

Silica,	33·863
Alumina,	6·589
Ferric Oxide,	1·232
Ferrous Oxide,	14·84
Manganous Oxide,	·246
Lime,	1·385
Magnesia,	18·988
Potash,	3·048
Soda,	5·274
Water,	15·07
	100·535

Loses 5·556 of water at 212°.

Substances similar in general appearance to Delessite occur in thin veins in granitiform-diorite in a quarry west of New Leslie, in Aberdeenshire, and at the Mull of Oe in Isla.

CHLOROPHÆITE.

1. This species, established by Dr Macculloch on specimens obtained by him from beneath the Scuir More ridge of the hill of Creag-na-Stiarnin in Rum, has never been analysed.

From a general similitude in appearance, Macculloch himself supposed that the saponite from Fife (? Elie) was the same, and he states that a specimen brought from Iceland by Major Peterson was "similar in all characters." Others have conjectured that certain substances more or less similar and similarly circumstanced were the same; but that all these conjectures were likely to prove correct was more than doubtful, seeing that they were based upon the substances having been said to be "chlorite-like minerals," while the chlorophæite of MACCULLOCH's description, and of the Scuir Mohr of Rum, is as little "chlorite-like" as it is possible for anything to be.

DANA, in classifying a mineral from Faröe, which was analysed by FORCHAMMER, under the head of "Chlorophæite," cautiously adds—"The chemical identity of the original chlorophæite of MACCULLOCH from Scuir More, with that of Faröe and the other localities has not yet been ascertained."

FORCHAMMER himself should have doubted their identity, seeing that he gives the mineral from Faröe a gravity of 1·809, while MACCULLOCH's mineral had a gravity of 2·02.

FORCHAMMER's mineral yielded—silica 32·85, protoxide of iron 21·56, magnesia 3·44, water 42·15; and is a totally different substance.

That MACCULLOCH's mineral, obtained at so near-home a locality as Rum, should, during the sixty years which have elapsed since its discovery, never have been analysed, was an enigma to the writer, until he noted the discoverer's statement, that the small quantities he himself obtained were got from fragments lying at the foot of the slope, for he "believed the Scuir-More to be everywhere inaccessible." A personal inspection of the locality, and some experience of the impossibility of landing at the spot except during the very calmest weather, also aided in the explanation.

At the Scuir-Mohr of Rum igneous rocks of an acidic, felspathic type (*syenite*, MACCULLOCH) have burst through and tilted strata of red "Cambrian" sandstone, while mixed beds of amygdaloid and basalt have overflowed these strata merely as far as the ruptured edges of the sandstone, and hang over their upturned slopes as a capping and encircling cliff.

At the northern end of the upturn, the angle of the tilt may be 45°; at the southern, near the point of Bridianoch, it is about 78°;—vast and unbroken sheets of sandstone rising here aloft to a height of about 800 feet.

Toppled pillars and lumps of amygdaloid from the impending cliff could find no resting-place on such a slope as this; and it was only when the waves had eaten out a shore terrace, and the gradually accumulating heap of *debris* crept up the gentler-angled portions of the slope, that the loose material assumed its own angle of rest. When the rich "trap-grass" clad it, however, the still falling materials were arrested before they reached the sea, to be grown over in turn, and serve to impede the fall of others; so that there has come to be a gradual sheathing and enveloping of the original rock-slope by a mass of loose material which is devoid of all attachment to its immediately sustaining base. Hence there are constantly recurring stone-avalanches,—the slope being over 1100 feet in height,—these leave gashes in its substance, the crossing of which broken ground may, through a slight disturbance, set much of the overhanging slope in motion.

Where grass-clad, the slope is, to well-tacketed boots, nothing beyond an unusually tough hand-and-foot scramble; but when the difficulties special to carrying heavy overbalancing hammers,—breaking rocks where there is little foothold,—and when that which is grasped is readily set upon the move,—be considered, it will not be wondered at that MACCULLOCH's mineral has never yet been analysed.

It moreover occurs in very small amount; it would take many days' work to obtain a sufficiency of the perfectly unaltered *green* mineral. The writer in three days' hard work obtained a sufficiency of what was either perfectly or moderately fresh.

To the excellent description of MACCULLOCH I can add nothing, except to emphasize some of his statements regarding that which is the most singular property of this mineral,—namely, the extreme rapidity with which it changes in colour when first exposed. From "the transparent yellow-green of the finest olivine" sometimes in the space of ten minutes it passes to a dark green-black; and in other specimens from the fine brown-orange of cinnamonstone to the rich brown and brilliant jetty-lustre of asphalt. By instantly after fracture wrapping up the one-half of an olive specimen tightly in repeated folds of paper, and keeping it as far as possible from exposure to air, heat, and light, I managed to retain the colour for about three weeks, only to see it lose it in half an hour when finally exposed. The other half became perfectly black after less than an hour's exposure.

Dr MACCULLOCH has noticed it scaling off in concentric crusts; the finest piece I obtained showed, when first broken, layers of successive depositions, some very light, some dark green; this specimen could not at first have been distinguished from the celadonite which will be noticed as occurring at Tayport, in Fife. During ten minutes' exposure to sunlight this specimen, which at first was rather dull, had assumed a lustre like that of obsidian; it had become in some of the layers dark green, in others black, and it had *rent through the whole thickness of its layers into rude hexagonal prisms.*

Specimens securely *bottled up* immediately upon extraction from the rock gave on analysis very little more of ferrous oxide than those which had been freely exposed; the change of colour therefore is not due to peroxidation of the ferrous oxide, but must be due to molecular change; and BREWSTER* has stated that he has optically determined that it is due to the mineral splitting up into a multitude of minute hexagonal prisms.

The material which I analysed was broken out of rude basaltic pillars; some of it, perhaps one-fifth, was green when placed in the bottles; none had changed further than to be rich asphalt brown, and this was still vitreous in lustre. It finally withers into a rusty brown or yellow friable lustreless powder.

The specimen was analysed ten days only after having been collected.

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* Reference lost.

On 1 · gramme—

Silica,	·356		
From Alumina,	.004		
	·360	=	36·
Ferric Oxide,			22·8
Ferrous Oxide,			2·462
Manganous Oxide,			·5
Lime,			2·52
Magnesia,			9·5
Alkalies,			trace
Water,			26·463
			100·254

Loses 19·227 *of the above water at* 212°. It was rapidly and perfectly dissolved in chlorhydric acid.

2. *The decomposed mineral.*—Dr MACCULLOCH was unable to ascertain the nature of the circlet of cliff which, like an Elizabethan collar, girdles the top of the Scuir. He supposed it to be inaccessible. It can, however, be easily turned at its north-west corner by approaching it from the landward side, and is then found to consist from top to bottom of repeatedly alternating bands of basalt and of amygdaloid.

The basalt is in rudely columnar forms, and contains very sparsely distributed amygdules of the chlorophæite, of about half the size of an almond. Its beds are six to eight feet in thickness.

The amygdaloidal beds are little over a foot in depth. This is a more vesicular rock than I ever saw even in Faröe. There has been very much more of steam-hole cavity than of solid material; the amygdules are of about the size of swan-shot, and they almost coalesce with each other on all sides. They are for the most part plugged with decomposed chlorophæite and chalcedony; those on the surface being empty, from the nodules having dropped from their casts,—which nodules may be gathered almost in handfuls at the foot of the cliff.

I worked into this amygdaloidal bed as far as seemed safe under the overhanging and by no means firmly attached columns, but did not reach to a part of the rock where the chlorophæite was fresh, and had therefore to content myself with analysing the altered mineral.

Its colour is rich chocolate brown, it is friable and very soft, having all the appearance of being altered; and as the chlorophæite of the dense basalt may, when exposed or within an inch of the surface of the rock, be seen to pass into the ochreous variety, there can be little doubt that the mineral is the same.

Of this altered chlorophæite, 1·003 grammes yielded—

Silica,	·171		
From Alumina,	·007		
	·178	=	17·746
Alumina,			·535
Ferric Oxide,			49·672
Ferrous Oxide,			2·147
Manganous Oxide,			1·196
Lime,			3·07
Magnesia,			3·988
Water,			21·818
			100·172

Loses 10·454 of the above water at 212°.

3. Greg and Lettsom, in their "Manual of Mineralogy," mention the Giant's Causeway as one of the localities where chlorophæite is to be found. I am happy to be able, by an analysis of the mineral found there, to show that this, which must have been of the nature of a conjecture from similarity of appearance, was a correct inference.

That which I analysed was obtained by Dudgeon and myself at the basaltic point immediately east of the Causeway; it filled small druses, and also coated chalcedony.

It was much softer than the nail, deep rich brown in colour, unctuous to the touch; its streak was shining, and its structure very minutely granular. Its specific gravity is 2·278.

1·11 grammes yielded—

Silica,	35·995
Alumina,	10·485
Ferric Oxide,	11·89
Ferrous Oxide,	1·626
Manganous Oxide,	·077
Lime,	5·15
Magnesia,	10·517
Potash,	·338
Soda,	·761
Water,	23·203
	99·997

It lost at 212° 14·156 of the above water. It was readily soluble in acids.

This is an aluminous chlorophæite. The specimen had been kept for several years, and may have lost some water.

HULLITE.

In the "Proceedings of the Royal Irish Academy," Mr HARDMAN has given a description and analysis of a mineral from Carnmoney Hill, Antrim, which he names after Professor HULL, but which *possibly* is merely a dessicated chlorophæite.

Mr HARDMAN states that "in physical characters it somewhat resembles the chlorophæite of MACCULLOCH, but is entirely different in composition." Seeing that no analysis of the chlorophæite of MACCULLOCH has ever been published, it is not easy to account for this statement; probably the analysis by FORCHAMMER of the mineral from Faröe was founded upon by Mr HARDMAN.

The description of the Carnmoney mineral *in all respects agrees* with the chlorophæite of the Giant's Causeway.

The analysis given is as in number 1.

	1.	2.
Silica,	39·437	35·061
Alumina,	10·35	9·211
Ferric Oxide,	20·72	18·421
Ferrous Oxide,	3·699	3·254
Manganous Oxide,	trace	
Lime,	4·484	3·987
Magnesia,	7·474	6·645
Water,	13·618	23·203
	99·782	99·782

Now, supposing this to be a chlorophæite partially dehydrated, either from exposure to a warm atmosphere, or from having been carried in the waistcoat pocket, or dried in the bath previous to analysis,—and suppose there is given to it the same quantity of water which the Causeway mineral contains, then the analysis would stand as in No. 2. This would clearly make it chlorophæite. The resemblance to this last mineral is altogether so close as to make it worth Mr HARDMAN's time to pick from the freshly broken rock, and secure in a bottle with greased stopper, a quantity of chips sufficient for a redetermination of the total water, and of the amount of loss at 212°.

1. The analysis of the following specimen, however, goes a long way to establish the specific individuality of Mr Hardman's mineral.

In the basaltic pillars embedded in the tufa of the Spindle at Kinkell, in Fifeshire, there very rarely occurs, filling small druses, a dark-green almost black mineral, which has in certain lights a slight brownish tint. It has a very minute granular structure, is dull, but the impression of the nail leaves a polished streak. It is very soft.

It is occasionally pseudo after analcime, and its associates are analcime, augite, and black lustrous titaniferous iron in angular fragments.

It was conceived to be possibly one of the substances called "chlorophæite from Fife" by Dr Macculloch, and was considered to be Delessite.

·653 grammes yielded—

Silica,	·239		
From Alumina,	·013		
	·252	=	38·591
Alumina,			17·337
Ferric Oxide,			15·97
Ferrous Oxide,			n. d.
Manganous Oxide,			1·562
Lime,			3·944
Magnesia,			8·646
Potash,			·67
Water,			13·476
			100·196

It lost 8·039 *of the above water at* 212°. It was readily decomposed by acids.

It was found to contain ferrous oxide, but there was not enough material for the determination of its amount. While this non-determination of the ferrous oxide leaves its composition in doubt, the claim of Hullite to rank as a species is considerably fortified by the circumstance of the analysis of this specimen having been performed so speedily after its extraction from the rock that there was no reason to believe that any more than a merely trifling loss of water had occurred.

It at the same time was so uniform in structure that it could not be regarded as a mixture, and its composition does not permit of its being ranked with either Delessite or chlorophæite.

SAPONITE.

From Igneous Rocks of Old Red Sandstone Age.

1. A little westward of the Tod Head, in Kincardineshire, there is a small boat-harbour called Gapol. Here the conglomerate rocks are broken through by, and interstratified with, igneous rocks; these are frequently amygdaloidal, especially on their upper surfaces. On the south-west side of the little harbour the rock is markedly serpentinous; and it contains between its beds veins of saponite of a fourth of an inch in thickness. The mineral has here a pale leek-green to a blackish-green colour, sometimes with bright red spots. It is unctuous and very soft. It frequently shows slickenside markings, which impart a false appearance of a fibrous structure, but it is devoid of any structure visible to a lens. Its specific gravity is 2·179.

The purest green was analysed; 1·3 grammes yielded—

Silica,	42·127
Alumina,	7·245
Ferric Oxide,	6·57
Ferrous Oxide,	·189
Manganous Oxide,	·129
Lime,	·798
Magnesia,	19·333
Potash,	·585
Soda,	2·094
Water,	21·069
	100·139

Loses 15·746 *of the above water at* 212°; insoluble silica, ·061 per cent. Was perfectly pure, but might have derived some of the soda from sea water.

Some specimens during the pounding became brown, and were rejected in the fear that they might contain some chlorophæite, the most marked feature of which, as above noted, is that it changes from green to brown with extreme rapidity upon exposure. This darkening or browning during the pounding is a feature of the saponite obtained from several localities.

The above, and all the specimens which were examined, were readily decomposed by acids.

In the cliffs immediately to the south of the Tod Head this mineral occurs filling amygdaloidal cavities of small size; here it has a minute and ill-defined scaly structure, and is so frequently pervaded with red or brown portions that it was not considered pure enough, or uniform enough, for being analysed further than by ascertaining the amount of the water; the determination of which showed that it was the same mineral.

2. From the parish of Kinneff, in Kincardineshire.—The road from Bervie to Stonehaven is, at a point a little north of where a side road branches to the church of Kinneff, cut on its west side into a small cliff of porphyritic amygdaloid,—the porphyritically disposed crystals being large twins of grey labradorite.

This porphyry has occasionally druses of considerable size, which are filled with large sheafy almost vermilion-coloured crystals of stilbite, smaller ones of Heulandite, and small radiating quartz crystals which sheath the two zeolites.

The quartz is sometimes also capped by spheres of saponite of about the size of shot. These spheres have a fibrous structure, a pale olive-green colour, and they are extremely soft.

Thrown into water they fall to pieces, expanding greatly; thus the specific gravity could not be ascertained. They were freed from quartz with extreme difficulty.

1·25 grammes yielded—

Silica,	42·1
Alumina,	5·948
Ferric Oxide,	4·963
Ferrous Oxide,	·18
Manganous Oxide,	·088
Lime,	2·15
Magnesia,	20·977
Potash,	·276
Soda,	·464
Water,	22·932
	100·078

Lost at 212°, 14·092 of the above water; insoluble silica, 1·117 per cent.

3. At the same locality there was also found the same mineral in a massive form. It occurred beneath the investing layer of quartz crystals; it was very soft and friable, and was unctuous to the touch. It had a grey colour mottled with purple, being in appearance similar to Naples' soap. Its specific gravity is 2·28.

·9 grammes yielded—

Silica,	42·5
Alumina,	5·88
Ferric Oxide,	4·91
Ferrous Oxide,	·12
Manganous Oxide,	·122
Lime,	2·13
Magnesia,	20·742
Potash,	·188
Soda,	·456
Water,	22·752
	99·798

Loses 14·52 of the water at 212°.

4. From Glen Farg, in Perthshire.—This specimen was given to me by the late ANDREW MURRAY, Esq. of Conland, as from the amygdaloid of that glen, where I have seen smaller pieces of it. The specimen was about two inches in length, and had been carved into the shape of a tiger. It was devoid of structure, much fissured, very soft, unctuous to the touch, semitransparent, and of an oily sap-green colour. Its specific gravity is 2·235.

1·3 grammes yielded—

Silica,	·472		
From Alumina,	·003		
	·475	=	36·538
Alumina,			9·396
Ferric Oxide,			2·852
Ferrous Oxide,			5·246
Manganous Oxide,			·153
Lime,			2·498
Magnesia,			21·615
Water,			21·681
			99·979

Loses at 212° 12·961 of the water; insoluble silica, 2·947 per cent. Was quite pure.

5. In making the curved cutting on the North British Railway, in Fifeshire, immediately landward of the Tay Bridge, beds some three or four inches in thickness of this substance of an impure description were come upon.

These beds were regularly interstratified with the igneous rock, here very friable and rotten. Apparently they consisted of a granular mixture of saponite with celadonite, and they carried softened and rounded granules of the rock matrix; their whole appearance conveyed the impression that they resulted from the decomposition of the rock.

A little eastward of this cutting a denser mass of the rock was laid open to afford a stance for the works connected with the building of the girders of the bridge. During the necessary blasting operations fine specimens of red chalcedony were obtained, and the rock here rarely afforded in its rents, veins and lumps of a pure saponite much resembling a soft steatite.

The colour is grass green, the structure dense and without any appearance of foliation; it is opaque, unctuous to the touch, and cuts like soft slate-pencil.

1·207 grammes yielded—

Silica,	42·839
Alumina,	4·828
Ferric Oxide,	6·496
Ferrous Oxide,	2·358
Manganous Oxide,	·2
Lime,	2·162
Magnesia,	21·812
Potash,	trace
Water,	20·698
	101·393

Was apparently quite pure; lost 13·868 of the water at 212°.

6. In clearing rock for the foundations of, and obtaining material wherewith to build a pier and patent slip at the harbour of Tayport, in Fife, some four miles from the last locality, the upper bed of the igneous rock was found to contain an abundance of agates, occasionally diversified by large nodules, which had more the appearance of celadonite than saponite, but which probably contained both.

The lower bed was rendered strikingly beautiful in appearance by the quantity of lustrous white calcite which it contained; this calcite was sheathed with a thin skin of brilliant red carnelian.

A cutting, opened up some 400 yards west of this, in laying out the railway between Tayport and Newport, afforded the following substances:—Fibrous silky pilolite, highly lustrous and beautifully white; yellow jasper, with a dendritic structure resembling corn-stooks; druses, lined with an opaque mammillated and banded celadonite, and having a central core of translucent waxy saponite, and long pipe-shaped amygdules totally filled with the last-named mineral.

In order to be enabled to contrast the composition of the saponite from this locality with that of the celadonite, the former was picked from the centre of those cavities in which it was invested by the opaque celadonite.

The mineral here is very translucent, devoid of structure, much flawed, resembles a green wax, has a somewhat brownish-green tint, and is easily bruised by the nail.

Its specific gravity is 2·283.

25 grains yielded—

Silica,	40·111
Alumina,	6·49
Ferric Oxide,	5·612
Ferrous Oxide,	2·369
Manganous Oxide,	trace
Lime,	2·008
Magnesia,	21·666
Potash,	·321
Soda,	·21
Water,	21·6
	100·387

Loses in bath 13·96 of the above water. I have lately found the mineral at this locality in thin veins, with a pseudo-fibrous structure due to interstitial fibrous calcite: in this form it is indistinguishable from the "Bowlingite" of Bowling Quarry.

In the foundation rock of Broughty Castle, on the north side of the Tay, saponite occurs both filling druses as a matted mass of fine scales, and also merely lining the druses in "rosettes" of minute crystals. These are of a brilliant dark-green colour, and in hexagonal combinations, apparently grouped like ripidolite. Their extreme softness is the only *physical* property by which they can be distinguished from that mineral. Their content of water at once determines their nature. In Roy Quarry, in Broughty Ferry, saponite occurs in quantity both in veins and filling small druses.

7. "From the Catkin Hills," in Lanarkshire.—This was given to me by the late Thomas Brown, Esq. of Lanfine. It occurred filling small druses in a dense igneous rock; its structure was minute scaly; its colour a bright green; when bruised or scratched the streak is nearly white; its specific gravity is 2·279.

1 · 3 grammes yielded—

Silica,	41 · 341
Alumina,	10 · 532
Ferric Oxide,	1 · 859
Ferrous Oxide,	3 · 836
Manganous Oxide,	· 087
Lime,	1 · 215
Magnesia,	21 · 073
Potash,	· 05
Soda,	· 37
Water,	19 · 481
	99 · 481

Lost 15 · 61 of the water at 212° ; insoluble silica, 3 . 98 per cent.

8. From the Catkin Hills.—This specimen was sent to me by Mr John Young, curator of the University Museum, Glasgow, as being a portion of the very specimen, an analysis of which was published by the late Wallace Young in the "Transactions of the Geological Society of Glasgow," as "a new fibrous green mineral."

The portion analysed was minutely fibrous in structure, but was also coarsely pseudo-fibrous, from interstitial fibrous calcite.

Its colour was dark leek-green; it was softer than the nail, giving almost a white streak, and it was in no way physically different from some of the specimens above described.

It yielded to acid (which was weakened so as to dissolve the interstitial calcite, with hardly any visible effervescence) 10 · 714 per cent. of calcite. With this amount of calcite its specific gravity was 2 · 288.

1 · 3 grammes freed from calcite yielded—

		Hannay.
Silica,	42 · 223	35 · 82
Alumina,	8 · 515	16 · 14
Ferric Oxide,	2 · 992	4 · 85
Ferrous Oxide,	4 · 876	6 · 99
Manganous Oxide,	· 073	
Lime,	· 919	4 · 87 calcite.
Magnesia	21 · 231	11 · 73
Water,	19 · 484	19 · 63
	100 · 313	100 · 03

Loses 14 · 76 of the water in the bath ; insoluble silica, 4 · 238.

Mr John Young also sent a portion of the same specimen to Mr J. B. Hannay, who has published an analysis of it (quoted) differing very markedly from the above; and he unites it with specimens of the same mineral (saponite) from Bowling Quarry—next to be noted—and has introduced it in the "Mineralogical Magazine" as a new mineral, under the name of *Bowlingite.*

Among the discrepancies which exist between Mr Hannay's analysis and the above, the most marked is the amount of magnesia, which, instead of the 21·231 per cent. obtained by me, amounts in his analysis to only 11·73. The late Mr Wallace Young, however, in his original analysis gives the quantity, according to one statement, at 20·95, according to another at 21·9.

9. From Bowling Quarry, on the Clyde.—The specimens were sent me by Mr Hannay as his "bowlingite" upon my writing him of the discrepancy in our analysis of the above mineral, and of my doubts as to "bowlingite" being anything else than saponite.

The specimens were not to be distinguished from the vein-saponite of Tayport, in Fife. They were in the form of portions of a vein of nearly one inch in width. Colour, dark grass-green; structure, fine foliated, but with pseudo-fibrous markings like slickenside. Scratches easily with the nail; streak very pale green, almost white. Contained imbedded crystals of calcite. Specific gravity, 2·308, being the average of four pieces chosen as being those most free of calcite.

Was scraped down with the back of a knife, all gritty particles (calcite) being so removed.

On 1·3 grammes—

				Hannay.
Silica,	·487			
From Alumina,	·008			
	·495	=	38·076	34·32
Alumina,			6·263	18·07
Ferric Oxide,			4·362	3·65
Ferrous Oxide,			4·975	6·81
Manganous Oxide,			·23	
Lime,			2·972	5·14 calcite.
Magnesia,			21·461	9·57
Potash,			946	
Soda,			106	
Water			20·477	22·70
			99·968	100·26

Loses at 212°, 12·315 per cent. of the water.

Mr HANNAY's analysis, which I have appended for comparison, shows (as in the case of the Catkin mineral) very marked discordance with mine in the magnesia and alumina.

Upon pointing this out to Mr HANNAY, and asking him to re-examine the substance, as I suspected some error had crept into his process, he furnished me with the following numbers as the average results of a new inquiry—*

Silica,	about	38
Alumina,	,,	20
Ferric Oxide,	,,	4
Ferrous Oxide	,,	7
Lime,	,,	3
Magnesia,	,,	10
Water,	,,	18

Which numbers are more accordant with those obtained by me, with still the marked exceptions of the magnesia and alumina.

The question of this being a new mineral depending upon the quantity of these two ingredients, I put a second portion of what Mr HANNAY had forwarded to me into the hands of Mr JOHN DALZIEL, who has worked in my laboratory for several years.

10. The specimen was hardly so pure as that previously examined, nor was it perhaps so absolutely free from calcite, though no effervescence could be detected when its powder was placed in acid.

1 · 301 grammes yielded—

Silica,	· 474		
From Alumina,	· 004		
	· 478	=	36 · 741
Alumina			5 · 35
Ferric Oxide,			5 · 938
Ferrous Oxide,			6 · 962
Manganous Oxide,			· 076
Lime,			3 · 056
Magnesia,			20 · 215
Potash,			· 494
Soda,			· 206
Water,			21 · 276
			100 · 314

Lost at 212°, 12 · 965 of the above water.

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* Undertaken I however understand by two of his students.

These numbers show that Mr Hannay's process must throw down his magnesia too early in the analysis, so that it is set down as alumina; and as the analysis by myself and Mr Dalziel of both the Catkin and the Bowling mineral agree with the others of saponite; and as the mineral is *absolutely identical therewith in appearance, in gravity, in hardness, in the peculiar manner in which the water is combined, and in all its physical and chemical properties,* we are forced to conclude that "bowlingite" can be nothing but saponite.

Saponite also occurs in very interesting specimens, which, according to information derived from Patrick Doran, from whom I purchased them, were obtained at Berry Glen, in Ayrshire.

Here the mineral is evidently crystallised, but the forms are minute, lustreless, and apparently somewhat rounded at the edges of the crystals. Small groups of minute crystals are disposed upon the summits of acicular crystals of "galactite" (natrolite).

The substances and order of deposition of these substances in the cavities which I have seen are:—"Cluthalite" (albite), cream-coloured galactite, red natrolite, saponite. The colour of the saponite is pale sap-green.

The same mineral (apparently) was found by Dr Lauder Lindsay in Corsiehill Quarry, on Kinnoul Hill, near Perth, disposed on the summits of radiating quartz crystals; here it is grass-green in colour, and of a minutely foliated structure; it also colours the quartz throughout, so as to form a *prase.*

Of the above localities affording saponite the following are all which afford any information as to the order of its deposition in the druses or rock-rents in which it is found:—

Kinneff—Heulandite, stilbite, quartz, saponite.
Tayport—Celadonite, saponite:—and Calcite, saponite.
Berry Glen—Cluthalite, galactite, natrolite, saponite.
Corsiehill Quarry—Quartz, saponite.

In the decomposition of the igneous rocks of the Old Red Sandstone age, therefore, the mineral (augite ?) whose decomposition yielded the saponite would appear to have been the last to be disintegrated, the felspars giving way first, to yield zeolites.

From Igneous Rocks of Secondary Age.

11. From the Storr, in Skye.—It here forms the outer—the first deposited—layer, sometimes half an inch in thickness, of some of the druses which occur in the rock at the east foot of the "Old Man of Storr." Occasionally it alone fills the druse. When other minerals are present they are superimposed upon it.

It is seldom that any other than chabasite is here present, but as this is the earliest formed of all the zeolites, all must be posterior in formation to the saponite.

This saponite is of a dark olive-green colour, passing into colourless. It is about the hardness of slate pencil—being here harder than at any other Scotch locality: it resembles a hard steatite. Its specific gravity is 2·296.

25 grains yielded—

Silica,	41·411
Alumina,	9·075
Ferric Oxide,	2·054
Manganous Oxide,	·107
Lime,	1·86
Magnesia,	22·8
Water,	23·433
	100·722

It lost 13·652 of the water at 212°. Some specimens crackled and fell to pieces in water.

12. From the Quiraing, Skye.—The pathway which leads from the Uig Road to the Quiraing looks down upon a little grass-clad valley, at a distance about half a mile from that road. Large masses of fallen rock lie in this valley, out of which there are, or rather were, to be obtained the finest gyrolites and the largest crystals of apophyllite to be found in Skye or indeed in Britain. Along with these saponite occurs filling druses. The mineral, when these are freshly opened, is quite pulpy, but a day's exposure hardens it.

It is then milk-white and curdy-looking, being of almost a friable structure. Sometimes it is quite pure; sometimes a small amount of microscopic crystals of stilbite (?) are impacted in the mass. It is dull in lustre, but polishes with the nail.

It falls to pieces in water.

1·499 grammes yielded—

Silica,	42·504
Alumina,	5·055
Ferric Oxide,	·852
Manganous Oxide,	·224
Lime,	3·274
Magnesia,	23·954
Potash,	·171
Soda,	·45
Water,	23·679
	100·136

Loses 15·536 of the water at 212°. Insoluble silica, 24·98 per cent.

13. The pathway to the Quiraing when followed northward from the last-mentioned locality winds round a projecting spur of rock; in this druses of about two inches in diameter occur, which are totally filled with saponite. Here its colour is dull wax yellow. It is translucent—weathering white and opaque, but it readily reabsorbs water and becomes again translucent. It falls to pieces in water, with somewhat of a burst, in a manner similar to bole. It is softer than the nail, may be cut out of the druses like cheese, and is altogether very similar in appearance to common soap.

1·29 grammes yielded—

Silica, ...	40·329
Alumina, ...	8·717
Ferric Oxide, . . .	1·972
Manganous Oxide, . .	·131
Lime, ...	2·8
Magnesia, . . .	21·71
Water, ...	24·338
	99·998

Loses 15·132 of the above water at 212°. Insoluble silica, 7·83 per cent.

Among the debris which occurs at the foot of a separate outlying ridge of rocks which lies north-east of the Quiraing saponite is found of the following colours:—Dark-brown, green, yellow, brown, light-green, and Venetian-red. It here is in dense structureless layers, also stalactitic and in minute crystalline spheres, but the forms are indistinct. A fine echo may give the name of Echoing Craig to this locality. The order of deposition of minerals here is—Saponite, chabasite, plynthite, calcite, Thomsonite, chabasite, apophyllite, analcime, mesolite.

It has thus to be remarked that while the saponite of the volcanics of Old Red Sandstone age has been the substance *last* deposited in the druses, that of the volcanics of the Lias and Oolite has been the *first*.

The inferences to be drawn therefrom will be considered in a future chapter on the Zeolites.

There can be little doubt that the "prasilite" of THOMSON ("Phil. Mag.," III. xvii. 416, 1840) is saponite. He describes it is a leek-green mineral, soft as Venetian talc, and with gravity = 2·311. It is stated to contain silica, alumina, ferric oxide, magnesia, and about 18 per cent. of water. Its locality also was the Kilpatrick hills.

The marked feature of saponite is the extreme ease with which it loses part of its water when heated, and the speed with which it regains it upon cooling. If a quantity of the mineral half-filling a closely-stoppered bottle be placed in the sun, the upper part of the bottle will speedily be bedewed with drops of water ; these will be reabsorbed, and the inside of the bottle be rendered perfectly dry by placing it in a cold situation. If some of the mineral be weighed, and then be carried for half an hour in the waistcoat pocket, it will be found to have lost from 6 to 7 per cent. of its weight thereby.

CELADONITE.

1. Occurs filling druses and coating chalcedony in close association with chlorophæite, in the basalt south of the Giant's Causeway.

Structure earthy, opaque ; colour, brilliant dark apple-green ; very soft, polishes with the nail. Specific gravity, 2 · 63.

Contained a little calcite, and was somewhat cavernous in spots, the cavities being slightly brown. The calcite and brown portions were cut away.

On 1 · 303 grammes—

Silica,	·73		
From Alumina,	·005		
	·735	=	56 · 408
Alumina,			2 · 138
Ferric Oxide,			14 · 073
Ferrous Oxide,			5 · 095
Manganous Oxide,			·23
Lime,			·601
Magnesia,			5 · 909
Potash,			8 · 832
Water,			6 · 796
			100 · 292

Loses 1 · 364 of the above water at 212°. Was almost *totally insoluble* in acids.

2. Occurs in bands of an inch or so in thickness in the amygdaloid of Scuir Mohr in Rum. These bands seem to be large flat cavities. They have sometimes an obscure laminated structure, but the substance is impalpable, somewhat greasy and not granular. The thin layers which coat the surfaces of the agates seem to be the same substance ; and it can be distinctly seen in the specimens around to be the colouring matter of heliotrope. Its colour is apple-green, and its specific gravity, 2 · 574.

1·301 grammes yielded—

Silica,	·74		
From Alumina,	·011		
	·751	=	57·725
Alumina,			·33
Ferric Oxide,			17·047
Ferrous Oxide,			3·729
Manganous Oxide,			·076
Lime,			·602
Magnesia,			3·843
Potash,			5·551
Soda,			·423
Water,			10·778
			100·204

Loses 5·99 of the above water at 212°. Was very slightly acted upon by acids.

I believe that the green "skin" of agates will prove to be celadonite, and not Delessite, as has been generally supposed.

3. Found in the railway cutting about 400 yards west of Tayport, Fife. It usually fills small druses of about an inch in size, in porphyritic amygdaloid. Its colour there is a bright light apple-green; it is opaque, dull, and its structure is granular under the lens. Its specific gravity is 2·59.

Occasionally the mineral only coats the druse in mammillated layers. It then somewhat resembles malachite, having lighter and darker bands of colour. The interior of these druses is filled with the saponite, of which an analysis is given. The saponite has a colour and structure markedly different from that of the celadonite. Its colour is much duller than that of the celadonite, and slightly dashed with brown; it has a greasy or waxy lustre, and is semitransparent, while the celadonite is quite opaque. There is no passage of the one mineral into the other, and their line of junction is quite sharp.

1·3 grammes yielded—

Silica,	·674		
From Alumina,	·011		
	·685	=	52·692
Alumina,			5·786
Ferric Oxide,			9·752
Ferrous Oxide,			5·366
Manganous Oxide,			·307
Lime,			1·163
Magnesia,			8·538
Potash,			6·212
Soda,			·388
Water,			10·485
			100·689

Loses 5·048 of the water at 212°. Is insoluble in acids.

In an upper bed of the igneous rock, close upon the spot where a patent slip has been cut, amygdules of the size of the fist occur among others of agate: these amygdules are totally filled, not with concentric layers of chalcedony, but with celadonite. The concentric structure is evidenced by brownish bands; the structure is granular, and the material of the layers is not so pure as that analysed above.

At Hare-Craig, on the opposite side of the Tay, this mineral rarely occurs in thin veins, of a very brilliant colour.

4. From the same line of railway, but near its western extremity, where it joins the Tay Bridge.

The mineral here is in veins, which frequently consist solely of a granular mixture of calcite with celadonite; the pure mineral was obtained with difficulty. It was granular, but never in mammillated coatings. Its specific gravity was 2·598.

It yielded on 1·3 grammes—

Silica,	·672		
From Alumina,	·011		
	·683	=	52·538
Alumina,			5·824
Ferric Oxide,			9·714
Ferrous Oxide,			5·4
Manganous Oxide,			·307
Lime,			1·292
Magnesia,			8·307
Potash,			6·497
Soda,			·635
Water,			10·413
			100·927

Loses 3·879 per cent. of the water at 212°.

DELESSITE.

	S. G.	Loss at 212°.	$\ddot{\mathrm{Si}}$.	$\dddot{\mathrm{Al}}_2$.	$\dddot{\mathrm{Fe}}_2$.	$\dot{\mathrm{Fe}}$.	$\dot{\mathrm{Mn}}$.	$\dot{\mathrm{Ca}}$.	$\dot{\mathrm{Mg}}$.	$\dot{\mathrm{K}}_2$.	$\dot{\mathrm{Na}}_2$.	$\dot{\mathrm{H}}_2$.	Total.
St Cyrus, Kincardine, . .	2·652	2·744	32·69	13·44	4·4	6·62	...	·86	28·77	...	...	13·25	100·02
Bowling Quarry, Dumbarton, .	2·573	5·7	32·	17·33	1·19	12·45	...	1·57	20·42	...	...	15·45	100·4
Dumbuck, do. . .	2·598	6·3	32·01	18·87	1·18	12·09	tr.	1·39	19·64	...	...	15·46	100·64
Long Craig, do. . .	2·656	4·678	30·93	15·32	3·16	15·31	·38	1·38	18·65	...	...	14·69	99·82
Elie, Fifeshire, ...	2·672	3·389	30·69	12·83	1·63	18·32	1·	1·59	18·6	·57	1·11	13·77	100·11
Average, ...	2·63	4·562	31·26	15·56	2·32	12·96	...	1·38	21·22	...	...	14·52	...
Formula, ...	...	...	31·53	16·28	2·8	12·61	...	...	21·02	...	...	15·76	...

CHLOROPHÆITE.

Scuir Mohr, Rum, . . .	...	19·227	36·	...	22·8	2·46	·5	2·52	9·5	tr.	tr.	26·46	100·25
Giant's Causeway, Ireland, . .	2·278	14·156	35·99	10·49	11·89	1·63	·08	5·15	10·52	·34	·76	23·2	99·99
"Hullite" (hydrated), . .	...	...	35·06	9·21	18·42	3·25	tr.	3·99	6·65	...	...	23·2	99·78

HULLITE.

Kinkell, Fifeshire, ...	...	8·029	38·59	17·34	15·97	n. d.	1·56	3·94	8·65	·67	...	13·48	100·2
Carnmoney (Hardman), . .	1·76	...	39·44	10·35	20·72	3·7	...	4·48	7·47	...	...	13·62	99·78
Average, ...	...	...	39·	13·84	18·35	3·7	...	4·48	8·06	...	...	13·5	...
Formula, ...	...	...	38·77	12·44	19·38	3·55	...	4·04	8·72	...	...	13·1	...

SAPONITE.

From "Old Red" Volcanics—													
Gapol, Kincardineshire, . .	2·179	15·746	42·13	7·25	6·57	·19	·13	·8	19·33	·58	2·09	21·07	100·14
Kinneff, do. (green), .	split	14·092	42·1	5·95	4·96	·18	·09	2·15	20·98	·28	·46	22·93	100·08
Do., do. (purple), .	2·28	14·52	42·5	5·88	4·91	·12	·12	2·13	20·74	·19	·47	22·75	99·79
Glen Farg, Perthshire, . .	2·235	12·961	36·54	9·39	2·85	5·25	·15	2·5	21·62	...	...	21·68	99·97
Wormit Bay, Fifeshire, . .	...	13·87	42·84	4·83	6·5	2·36	·2	2·16	21·81	tr.	...	20·7	101·39
Tayport, do., ...	2·282	13·96	40·11	6·49	5·61	2·37	tr.	2·01	21·67	·32	·21	21·6	100·38
Catkin Hills (scaly), ...	2·279	15·61	41·34	10·53	1·86	3·84	·09	1·22	21·07	·05	·37	19·48	99·48
Do., (fibrous) ("Bowlingite"),	2·288	14·76	42·22	8·52	2·99	4·88	·07	·92	21·23	...	...	19·49	100·31
Bowling, Dumbarton ("Bowlingite")	2·308	12·315	38·08	6·26	4·36	4·98	·23	2·97	21·46	·95	·11	20·48	99·96
Do., do. (Mr Dalziel),	...	12·965	36·74	5·35	5·94	6·96	·08	3·06	20·22	·49	·21	21·28	100·31
From Secondary Volcanics—													
Storr, Skye (olive), . . .	2·296	13·652	41·41	9·08	2·05	...	·11	1·86	22·8	...	...	23·43	100·72
Quiraing, Skye (white), . .	split	15·536	42·5	5·06	·85	...	·23	3·27	23·95	·17	·45	23·68	100·14
Do., do. (yellow), . .	split	15·132	40·33	8·72	1·97	...	·13	2·8	21·71	...	...	24·34	99·99
Average, ...	2·272	14·22	40·63	7·18	3·96	2·38	...	2·14	21·43	...	...	21·76	...
Formula, ...	...	...	40·81	7·5	3·88	2·62	...	2·04	20·61	...	...	22·73	...

CELADONITE.

Scuir Mohr, Rum, ...	2·574	5·99	57·72	·33	17·05	3·73	·08	·6	3·84	5·55	·42	10·78	100·2
Tayport, Fifeshire, . . .	2·59	5·048	52·69	5·79	9·75	5·37	·31	1·16	8·54	6·21	·39	10·48	100·68
Wormit Bay, ...	2·598	3·879	52·54	5·82	9·71	5·4	·3	1·29	8·31	6·5	·64	10·41	100·93
Giant's Causeway, Ireland, . .	2·63	1·364	56·41	2·14	14·07	5·09	·23	·6	5·91	8·83	...	6·79	100·29
Average, ...	2·598	...	54·84	3·52	12·64	4·9	...	·89	6·65	7·	...	9·62	...
Formula, ...	...	...	54·05	3·83	11·94	5·4	...	...	6·76	7·88	...	10·14	...

The above tabulation presents clearly to the eye the distinctive features of these five volcanic minerals, which are arranged therein in the order of their content of silica; and as no such extended research into the composition of these minerals has before been published, it is necessary, in the first place, to consider the formula of each.

This in the following tables is done by giving in the first column the average composition. This is followed by the calculation of atoms—the last column giving the percentages calculated from the formulæ which stand below :—

Delessite.

		Atoms.			
Silica,	31·26	1·041	3·15	3	31·53
Alumina,	15·56	·302	1	1	16·28
Ferric Oxide,	2·32	·029			2·8
Ferrous Oxide,	12·96	·36	4·3	4	12·61
Magnesia,	21·22	1·061			21·02
Water,	14·52	1·614	4·9	5	15·76

Formula—

$$(\dot{Fe}^{\frac{1}{4}}\,\dot{Mg}^{\frac{3}{4}})\,{}^{2}\ddot{Si}^{2} + (\dddot{Al}_{2}{}^{\frac{1}{10}}\,\dddot{Fe}_{2}{}^{\frac{9}{10}})\,\ddot{Si} + 3\dot{H}_{2} + 2\dot{Mg}\dot{H}_{2}\,.$$

Or generally—

$$(\dot{R}^{2}\,\dddot{R}_{2})^{3}\,\ddot{Si}^{3} + 3\dot{H}_{2} + 2\dot{Mg}\dot{H}_{2}\,.$$

Or atoms—

$$\dot{R}\ 4,\ \dddot{R}_{2}\ 1,\ \ddot{Si}\ 3,\ \dot{H}_{2}\ 5\,.$$

Chlorophæite.

		Atoms.			
	36	1·2	1·2	3·5	36·24
Alumina,	10·54	·205	·35	1·	8·87
Ferric Oxide,	12·04	·15			13·81
Ferrous Oxide,	2·04	·057	·7	2·	2·42
Lime,	3·83	·145			3·8
Magnesia,	10·	·5			10·01
Water,	25·83	2·87	2·87	8·	24·85

Formula not evident.

Atoms—

$$\dot{R}\ 4\,,\ \dddot{R}_{2}\ 2\,,\ \ddot{Si}\ 7\,,\ \dot{H}_{2}\ 16\,.$$

Hullite.

On the average, taking the ferrous oxide as in Mr HARDMAN's analysis—

		Atoms.				
Silica,	39·	1·3	7·89	8	38·77	39·67
Alumina,	13·84	·265	3	3	12·44	17·03
Ferric Oxide,	18·35	·23			19·38	13·22
Ferrous Oxide,	3·7	·103	4·04	4	3·55	3·63
Lime,	4·48	·16			4·04	4·13
Magnesia,	8·06	·403			8·72	8·92
Water,	13·5	1·5	9·09	9	13·1	13·40

Formula—

$$(\dot{Fe}\,\dot{Ca}\,\dot{Mg})^4\,(\dddot{Al}_2{}^{1\frac{1}{2}}\,\dddot{Fe}_2{}^{1\frac{1}{2}})^3\ddot{Si}^8 + 9\dot{H}_2\,.$$

Or generally—

$$\dot{R}\,4\,,\ \dddot{R}_2\,3\,,\ \dddot{Si}\,8\,,\ \dot{H}_2\,9\,.$$

The Kinkell specimen gives the formula—

$$(\dot{Fe}\,\dot{Ca}\,\dot{Mg})^4\,(\dddot{Al}_2{}^2\,\dddot{Fe}_2)^3\ddot{Si}^8 + 9\dot{H}_2$$

and the numbers in last column. These agree better with the results of that analysis than do those of the first formula with the average of both analyses.

Saponite.

		Atoms.				
Silica,	40·63	1·354	1·354	7·1	7	40·81
Alumina,	7·18	·14	·19	1·	1	7·51
Ferric Oxide,	3·96	·05				3·88
Ferrous Oxide,	2·38	·066	1·33	6·5	6·5	2·62
Lime,	2·14	·076				2·04
Magnesia,	21·43	1·07				20·61
Water,	21·76	2·42	2·42	12·75	13	22·73

Formula—

$$(\dot{Fe}\,\dot{Ca}\,\dot{Mg})^6\,\ddot{Si}^6 + (\dddot{Al}_2{}^3\,\dddot{Fe}_2)\,\ddot{Si} + 13\dot{H}_2\,.$$

Or generally—

$$6\,\dot{R}\,\ddot{Si} + \dddot{R}_2\,\ddot{Si} + 13\,\dot{H}_2.$$

Or atoms—

$$\dot{R}\,6\,,\ \dddot{R}_2\,1\,,\ \ddot{Si}\,7\,,\ \dot{H}_2\,13.$$

Celadonite.

		Atoms.				
Silica, . .	54·84	1·828	1·828	8	8	54·05
Alumina, . .	3·52	·07	·228	1	1	3·83
Ferric Oxide, .	12·64	·158				11·94
Ferrous Oxide, .	4·9	·136	·616	3	3	5·4
Magnesia, . .	6·57	·332				6·76
Potash, . .	7·65	·148				7·88
Water, . .	9·84	1·07	1·07	4·7	5	10·14

Formula—

$$(\dot{Fe}^{\frac{1}{4}}\,\dot{Mg}^{\frac{1}{2}}\,\dot{K}_2^{\frac{1}{4}})^3\,\ddot{Si}^6 + (\dddot{Al}_2^{\frac{1}{3}}\,\dddot{Fe}_2^{\frac{2}{3}})\,\ddot{Si}^2 + 5\dot{H}_2\,.$$

Or generally—

$$3(\dot{R}\,\ddot{Si}^2) + \dddot{R}_2\,\ddot{Si}^2 + 5\dot{H}_2\,.$$

Or atoms—

$$\dot{R}\,3\,,\ \dddot{R}_2\,1\,,\ \ddot{Si}\,8\,,\ \dot{H}_2\,5.$$

In the above investigation every substance, the nature of which was at all doubtful, of which I could obtain a sufficiency for analysis was examined.

In applying the results of the examination to the consideration of the geognostic relations of these minerals, those of the first or true chlorite type may be dismissed in few words.

With the exception of the occurrences of chlorite at the Girdleness and at Rubislaw in granite, the minerals of the first class are to be found *only in metamorphic rocks.*

Glauconite, occurring generally in rock which is believed to be of recent origin, may, by its occurrence, aid somewhat in the assigning the age of certain doubtful strata.

The second group, which I have called the saponites, belong *solely to igneous rocks;* and, from the mode of their occurrence, there is no room for doubt that *they result from the alteration of certain of the constituents of these rocks*—augite and olivine in all probability.

As regards our power of distinguishing them from each other, this is by no means so difficult as their want of form and general similarity of appearance would at first sight lead one to suppose.

Delessite can be distinguished from chlorophæite by its dull lustre, its minutely granular structure, its opacity, and its colour—in the field; and rapidly in the laboratory by its much higher gravity, its much smaller loss at 212°, and much smaller total content of water.

From the specimen of Hullite found at Kinkell, I could not by physical properties undertake to distinguish it;—the darker varieties of Delessite at least much resembled that specimen.

From saponite, Delessite can be distinguished by its dark colour and granular structure and its opacity; and in the laboratory by its high gravity and its water.

From celadonite it could not be distinguished either by its structure or opacity, or by its gravity, or satisfactorily by its water content; but its colour, and its solubility in acids, at once suffice to separate the two.

Chlorophæite is readily recognised; when fresh it resembles a green jelly,—when weathered it equally resembles drops of asphalt.

The Kinkell Hullite resembles a dark Delessite, and therefore does not resemble chlorophæite.

Saponite, in its usual green form, is easily known; its extreme softness, greasy lustre, great translucency, and soapy structure suffice to define it in the field; the extreme readiness with which it parts with and regains so large a quantity of water equally suffices in the laboratory, while its low gravity is of itself characteristic.

The white variety is by no means so readily identified; halloisite, conite, the magnesian carbonate of lime, agaric mineral, and a peculiar superhydrated vein-serpentine, all closely resemble it.

Celadonite may at once be known by its insolubility in acids; its loose granular or mammillated structure, its perfect opacity, and brilliant colour, are likewise well-marked characters.

Such are the minerals occurring in Scotland, which are without question to be referred directly to one or other of the above species. I now note certain which cannot be so unhesitatingly classed under any of these heads, and two which appear to be new.

1. About one hundred yards above the bridge of Cally, in Perthshire, a singular bedded boss of friable trap protrudes out of the north bank of the Ardle. This contains amygdules from the size of shot to that of a bean, filled with a dark, greenish-brown, soapy substance, which is much impregnated with both calcite and chalcedonic quartz. Its structure is minutely granular.

1 · 499 grammes gave—

Silica,	· 785		
From Alumina,	· 026		
	· 811	=	54 · 702
Alumina,			· 83
Ferric Oxide,			2 · 599
Ferrous Oxide,			9 · 82
Manganous Oxide,			· 24
Lime,			5 · 71
Magnesia,			16 · 34
Water,			10 · 82
			100 · 467

Loses 6 · 101 of the water in the bath; insoluble silica, 7 · 66 per cent.

The above is the analysis of the substance, purified as far as possible from its two associates, and it accords fairly well with celadonite; but I incline to regards its apparent similarity therewith as being fortuitous, and probably the result of imperfect separation from quartz, and I conceive that the mineral may actually be saponite, impure from chalcedonic admixture.

I take this view from its colour and lustre, from its being partly soluble in acids, and from finding that some portions gave a loss in bath of 12 · 447 per cent. of water, with about 9 per cent. of residual water; so if the substance analysed be not impure saponite, saponite itself must here occur.

2. In crystalline granular limestones which do not manifest well-marked features of alteration there are no minerals to be found, if we except such a common one as pyrite; but there are frequently also to be seen plates or interrupted layers of an ill-defined green mineral generally in too intimate a state of intermixture with the lime, or with included portions of the matrix, to permit of separation for analysis.

I was so fortunate as lately, in company with Dr Aitken of Inverness, to obtain some of this substance from the limestone quarry of Reelig, near the Beauly Firth; this was sufficiently pure, and no more than so, for analysis.

Its colour is a somewhat dark green, its structure is granular, or foliated crystalline. It is softer than the nail. Its appearance is intermediate between chlorite and saponite. In pounding it became brown. It was associated with a slaty steatite, which contained layers of minute crystals of talc. Belts of banded and mottled steatite, like Naples' soap in appearance, also occur in the lime, carrying rarely crystals of calcite.

1·3 grammes of the green mineral yielded, when fused with Fresenius' flux—

Silica,	·596		
From Alumina,	·005		
	·601	=	46·23
Alumina,			13·159
Ferric Oxide,			1·882
Ferrous Oxide,			3·073
Manganous Oxide,			·384
Lime,			7·753
Magnesia,			14·153
Water,			13·308
			100·142

Loses in bath 7·657 of the above water.

This looks very like a new mineral, but upon treating some of it with chlorhydric acid the greater part dissolved, leaving a small quantity of white silvery scales.

As saponite is soluble in chlorhydric acid, while talc is not, and as an admixture of a little talc with saponite would give a composition similar to the above, there can be little doubt that this is some such mixture.

The two substances which appear to be new are the following. I name them from their localities :—

BHRECKITE

Occurred in very small quantity in a large granitic boulder, which lay upon the west slope of Ben Bhreck, Tongue, Sutherland, and which I have already referred to as containing amazonstone and many other minerals.

Is a bright apple-green, minutely granular or scaly powder, nearly as brilliant in colour as celadonite. Is soft and friable.

Was disposed upon the surface of quartz crystals, and therefore was one of the last substances to solidify; its immediate associates were specular iron and strontianite.

The small quantity analysed was to all appearance pure.

On ·484 grammes—

Silica,	·166		
From Alumina,	·003		
	·169	=	34·917
Alumina,			7·158
Ferric Oxide,			12·713
Ferrous Oxide,			2·105
Manganous Oxide,			·414
Lime,			16·082
Magnesia,			8·264
Water,			17·768
			99·655

Of the above water 1·033 was lost at 212°. There were traces of alkalies, but there was not enough material to determine them upon.

The mineral was freely soluble in chlorhydric acid.

		Atoms.			
Silica,	34·917	1·164		8	36·28
Alumina,	7·158	·14	·3	2	7·78
Ferric Oxide,	12·713	·16			12·1
Lime,	16·082	·574	1·04	7	17·69
Magnesia,	8·264	·413			8·46
Water,	17·768	1·974		13	17·69

Formula—

$$(\dot{Ca}^{\frac{6}{10}}\ \dot{Mg}^{\frac{4}{10}})^{7}\ \ddot{Si}^{6} + 2\,(\dddot{Al}_{2},\ \dddot{Fe}_{2})\ \ddot{Si} + 13\dot{H}_{2}\,.$$

Or Atoms—

$$\dot{R}\,7\,,\ \dddot{R}_{2}\,2\,,\ \ddot{Si}\,8\ \dot{H}_{2}\,13\,.$$

RUBISLITE.

This substance I found along with Professor Nicol in a deep part of the quarry of Rubislaw, near Aberdeen.

It was imbedded along with crystals of muscovite in an exfiltration vein.

It occurred in a solid lump, and also forming a "corded structure," pervading felspar, identical in appearance with that noted by me in felspar: it thus occupied the position of the oligoclase or albite which usually forms that structure.

Its colour was dark green, its lustre dull, its structure was minutely foliated to granular, its particles could be separated from each other by the nail, which left a streak paler than the original colour.

It was readily and totally decomposed by chlorhydric acid, silica alone being left.

Its specific gravity was 2.442.

1·3 grammes yielded—

Silica, . . .	·488		
From Alumina, .	·004		
.	·492	=	37·846
Alumina, ...			10·924
Ferric Oxide, ...			9·84
Ferrous Oxide, ...			9·005
Manganous Oxide, . .			·461
Lime, ...			4·221
Magnesia, ...			8·
Potash, ...			3·334
Water, ...			16·132
			99·763

Loses in the bath 8·571 of the above water. Before the blowpipe semi-fused into a vesicular brown slag.

This gives in atoms—

		Atoms.				
Silica, . .	37·846	1·2615		22	22	37·42
Alumina, .	10·924	·212	·325	6	4	11·68
Ferric Oxide,	9·84	·123			2	9·06
Ferrous Oxide,	9·005	·25	·885	16	5	10·19
Lime, . .	4·221	·151			3	4·75
Magnesia, .	8·	·4			7	7·93
Potash, .	3·334	·071			1	2·67
Water, .	16·132	1·792		32	32	16·31

General Formula—

$$8\,(\dot{\mathrm{Fe}}\,,\,\dot{\mathrm{Ca}}\,,\,\dot{\mathrm{Mg}}\,,\,\dot{\mathrm{K}}_2)\,\ddot{\mathrm{Si}}+3\,(\dddot{\mathrm{Al}}{}_2^{2}\,\dddot{\mathrm{Fe}}_2)\,\ddot{\mathrm{Si}}+16\,\dot{\mathrm{H}}_2\,.$$

Or Atoms—

$$\dot{\mathrm{R}}\,8\,,\;\dddot{\mathrm{R}}_2\,3\,,\;\ddot{\mathrm{Si}}\,11\,,\;\dot{\mathrm{H}}_2\,16\,.$$

Possibly there might have been some slight admixture of felspar. The replacement in the protoxides is confused.

This is very like a Hullite in which much of the iron is in the ferrous condition.

These two substances are noticed in the hope of more of them being found; the quantity obtained of both of them was very small.

SUPPLEMENT TO SAPONITE.

In a letter from Professor KING, received since the foregoing analyses of saponite were executed, he writes:—

"According to HAUGHTON, saponite occurs with serpentine in Cornwall. Some specimens I collected there I take to be the same mineral; but it is not 'soft like butter or cheese'—it is hard, something like serpentine, and may be actually a white or cream-coloured serpentine. The specimen laid by for you will settle the point. I should like to see your saponite."

This sentence led me to compare the specimens which I have of what I have called the "super-hydrated vein-serpentine" (page 109) with the descriptions of saponite given by DANA,—and my analyses of these specimens with the column of analyses to be found at page 472 of his work.

While the physical properties assigned to saponite by DANA agree perfectly with those of the specimens which I have analysed, and therefore warrant my assigning the name to the Scotch specimens, it cannot be said that the claim of certain of DANA's specimens to the name is altogether beyond a doubt, and this on account of the most characteristic of the features of the Scotch mineral—namely, the low temperature at which it parts with some of its water—not having been observed in the specimens hitherto ranked as saponite. When, however, the *analyses* given by DANA are considered, there is no room for doubt that some of the substances analysed should not have found a place there, and there is even room for doubt if any but the *thalite* of OWEN should.

Nothing, but their having suffered such a loss of water as I have pointed out as likely to occur through exposure to heat during carriage, could entitle us to associate under one name substances varying in their content of water to such an extent as from 10·5 to 20·66 per cent.—a variation which so far explains, though it hardly justifies, DANA's remark, that "analyses give naturally no uniform results for such an amorphous material." Had it been said that the name had been applied to substances which, filling the steam-holes of volcanic rocks, were unquestionably the products of change or degradation,—possibly not always of the same nature, or of the same material,—such a remark might legitimately be made. It is, however, a fairer inference that the analyses give no uniform results, because *different substances* have been included under one name.

And this inference is borne out in a marked manner by a consideration of the peculiar substance which fills the rents in serpentine rocks; and this consideration leaves little or no doubt that the so-called steatite or seifenstein from Cornwall and from all serpentine rocks must be withdrawn from the species, and that the name must, as I have shown above, be in future confined to one of the materials which plug the amygdules or rarely the rents of *igneous rocks.*

The suggestion of DANA's that as, if we suppose the alumina to be present as *kaolinite,* the rest is a silicate allied to *aphrodite,—as if the mineral were a mixture of the two,*—I cannot regard as sound, for the two reasons that, according to DANA himself, neither kaolinite nor aphrodite occur in volcanic rocks (nothing of the kind is to be seen in the Scotch ones), and because, as he himself states, kaolinite is not decomposed by acid, while saponite is.

Any admixture "as kaolinite," with a mineral soluble in acid, would after treatment therewith disclose itself by remaining as an insoluble residue.

The features, so far as I have yet attained to the recognition of them, whereby this super-hydrated vein-serpentine can be discriminated from saponite, are the very much smaller amount of its loss of water when heated,—its smaller content of water,—and a peculiar opalescence and girasol appearance, which it presents, when transparent varieties are looked through.

In five analyses of these "vein-serpentines" from Scotland which I have executed, I have found the quantity of total water to lie between 15·16 and 16·58 per cent.; and of this the loss at 212° ranged from 1·63, which was that of the lowest total, to 3·53, which was that of the highest.

The deduction of these losses, it will be observed, brings the residual water to about the amount normal to serpentine.

Such were the conclusions I had arrived at when the receipt of a box of Irish serpentines from Professor KING, containing specimens of the "saponite veins" of Cornwall collected by himself, enabled me by analyses to speak with more precision on the matter.

The specimens of the Cornish "saponite" were at once seen to be physically very similar to the paler-coloured vein-serpentines of Portsoy. Being apparently somewhat weathered they were opaque, and the girasol appearance could not be seen.

A weathered vein from the serpentine of Polmally, in Glen Urquhart, which was very similar, was analysed along with this Cornish saponite.

It is not necessary here to quote more than the content of water, and loss thereof at 212°: this was—

	Total water.	Loss at 212°.
Mineral from Cornwall, . .	14·133	1·166
,, ,, Polmally, . .	15·162	1·626

This, taken in conjunction with a general accordance with their other components, shows that these specimens are similar to other vein-serpentines, and are quite distinct from the mineral which occurs in volcanic rocks.

As the specimen sent by Professor KING is quite similar to other smaller ones which I have seen in the Lizard serpentine, there is every probability that the mineral analysed by KLAPROTH, SVANBERG, and HAUGHTON was the same; and that of the substances classed under the head of saponite by DANA, only those narrated as filling geodes in volcanic rocks properly fall under the title.

SUPPLEMENT TO CHLORITE.

I have lately observed what I believe to be a chloritic mud occurring in a form in which it bears a great resemblance to glauconite.

The circumstances of its occurrence are of much interest, and the explanation of these circumstances is attended with no small amount of difficulty.

Immediately to the north of the village of Callander there is a cliff of conglomerate of the Old Red Sandstone; this is here formed of nodules, from the size of a walnut to that of the fist, of gneiss, mica slate, and quartz,—rocks of the immediate neighbourhood.

Rarely thin interstrata of a finer almost of a sandy grain,—more fitted for building purposes,—occur to the north-eastward of the village.

In several small quarries, opened with a view to work these gritty beds, the characters of the conglomerate may be studied. It has somewhat of a vitrified aspect, and is more broken up by "backs" and "cutters" than is usual to that rock. The dip is to the north-east; the backs run along the strike at distances of about six feet from each other; while the cutters, lying generally at right angles thereto, are much more closely adjacent to each other.

The backs, in those cases in which they have stood open, are invariably filled with one of the varieties of the substance to which the names of *reddle*, or *keely* or *keels* has been attached: the cutters are as invariably lined, and usually no more than lined, on each side with sheets of cockscomb barytes, which sometimes carry vitreous copper, malachite, and calcite.

The dull red of the vertical sheets of reddle is everywhere besprinkled with spots and blotches of a vivid green, of the colour of glauconite,—these spots are circular in form, or consist of a number of confluent circles, each circle being of about the size of a large bean.

The contrast of these colours is so striking as to arrest the attention of the passer-by; it is found upon examination to be due to the occurrence in the pseudo-vein of reddle, of "concretions" of granular pale purple carbonate of lime, of a discoid form; and to these concretions being invested by the glauconite-like material, disposed in a laminated manner.

Portions of the calcareous concretions,—of their green coating,—and of the reddle, were examined in the laboratory, after isolation each from the others.

The concretions did not appear to have any structural arrangement of particles, being similar to a very fine-grained saccharine marble; they dissolved readily and totally in acid, without leaving any save a glauconitic residue; and neither they nor their associates contained any trace of barytes.

The glauconite-like matter was found to be insoluble in all acids; but after treatment therewith and agitation in much water, it separated into minute colourless pearly scales (like mica), and a green powder, which was also minutely scaly.

The reddle had a laminated arrangement of its particles parallel to the sides of the vein; it resembled a red sandy clay, and glistened with minute scales of mica. Treated with chlorhydric acid it yielded readily a ferruginous solution, but left behind the greater part of its bulk as a green powder, similar in appearance, and also in its insolubility similar to that which presented itself originally with a green hue.

From the evident admixture of scales of mica, it may be doubted if an analysis of these green powders—probably identical—would definitely disclose their nature; but the above chemical features sufficiently show that they cannot be any one of the saponites, unless it be celadonite, and their being the latter is contradicted by their scaly structure.

Their insolubility in acids equally proves that they cannot be glauconite; and, having regard to the occurrence in the conglomerate of quartz nodules with a chlorite which is very similar to that of Cruach Ardran and the hills surrounding it, there is every probability that the green portion consists of chlorite alone.

While the impurity of this substance prevents a more accurate determination, enough has probably been attained to, in the direction of indicating several points of marked interest connected therewith.

The following questions present themselves for being answered:—

By what process were these veins filled? The ready reply,—neither by infiltration nor injection, but by exfiltration,—goes but a little way. Conglomerated rocks are more pervaded by a system of *inosculating holes* than by fissures,—but I broke many pieces of the rock without being able to detect in its cavities any green matter in the course of being transported to its resting place in the vertical rents; but an exfiltration of reddle-like matter may be observed, and this may obscure a concomitant chloritic transfusion.

Then, *What is the action whereby the segregating calcareous matter repels the hematitic,*—thus operating as a pseudo-bleacher ?

And lastly, *How comes it that the one set of rents are lined with baryte, with vacuous interspaces; while that which lies at right angles thereto contains no trace of baryte, but is totally filled with a clay-like material?*

An explanation which may be said to lie upon the surface—namely, that the first mentioned set had been of earlier formation, and had been the seat of a process which had reached its termination before the formation and filling up of the latter,—does not meet the facts of the case, because the rock-rents which form the "backs" seem to have been antecedent to those existing as "cutters"; for the former pass numbers of the latter, while these but very seldom cut across the former.

The rock seems to be *still* purveying hematitic and chloritic matter to the cracks which form its "faces";—*is there a polarity in the guidance of its decomposition,* acting so as to fill its minor and secondary rents with barytes and with copper,—enabling them at the same time to reject the slimy plug which chokes the backs, that they may at least aspire to the dignity of being true mineral veins ?

Some questions of weighty mining import might possibly be answered through a study of this narrow field;—the points of chief mineralogical interest are the occurrence of a chloritic mud in a form simulating glauconite,—and the singular manner in which a large quantity of chlorite may be entirely masked by a comparatively small quantity of peroxide of iron.

IV.—*On some Physiological Results of Temperature Variations.* By JOHN BERRY HAYCRAFT, M.B., C.M., B.Sc., Assistant to the Professor of Physiology (Edin. Univ.). Communicated by Professor TURNER, one of the Secretaries to the Society. (Plate I.)

(Read 17th February 1879.)

While trying to verify by actual statistics some of the "Laws of Population" first enunciated by MALTHUS, a curious fact was observed, viz., that some seasons of the year are more prolific in the number of births than others.

This led to the further investigation of the subject, the results of which are before the Society.

In pursuing this inquiry, data were drawn from the monthly returns of births, deaths, and marriages (Scotland). I may here express my hearty thanks to Dr WILLIAM ROBERTSON, for much kindness shown in furnishing the necessary reports.

Two courses were open: to take the births of the whole of Scotland, where the illegitimate are mixed together with the legitimate, therefore vitiating the results when compared with the marriages; or to take only data from the legitimate births of "The Eight Large Towns of Scotland," where seasonal variations in the number of inhabitants are continually taking place, there being always more in winter than in summer "in town."

It was deemed advisable to avoid both fallacies by working with both sets of data, the one correcting the other.

The data quoted in this paper are those, however, of the eight large towns alone, those of Scotland generally not being given for sake of brevity. They will be, notwithstanding, quoted once or twice to correct the other.

In all cases large numbers were used, and these numbers taken never from the single year's returns alone, but always from an average of at least ten.

On studying the monthly returns of "births," it is seen that there are some months in the year in which more births occur than others.

Thus in April of *every* year there are more than in November.

Averaged Monthly Returns of Births of Years (1866–1875) *inclusive, Corrected to equal Months of* 30·42 *Days.*

January, = 3154 births (legitimate).
February, = 3057 „ „
March, = 3227 „ „
April, = 3387 „ „

May, = 3290 births (legitimate).
June, = 3289 ,, ,,
July, = 3107 ,, ,,
August, = 2915 ,, ,,
September, = 2979 ,, ,,
October, = 3072 ,, ,,
November, = 3001 ,, ,,
December, = 3050 ,, ,,

Average, = 3127.

If the births are diagramatically represented, the ordinates being the number of births, and the abscissæ the time of the year in months, a curve is produced.

Now every year this curve may be seen recurring with striking regularity, there being always some months in the year which are fertile in births, and others which are comparatively barren. There must be a cause, or causes, working with equal regularity to produce it.

It is our task to investigate these, and, if possible, to ascertain their value.

On thinking over the factors which might exert an influence upon the number of births, it is natural that the number of "marriages" (which likewise varies in the different months) should be first thought of. On reference (see Chart I.) the marriage curve is seen to be of quite a different character from that of the birth curve. It may here be remarked that all the charts are prepared from the averaged returns in the same way: the abscissæ are taken as months and ordinates as numbers of births, &c. The "birth curve" rises to a maximum and then falls once in every year. The "marriage curve" exhibits two striking and sharp maxima recurring every year. Obviously at any rate the marriage curve is not the only factor. It is, as we shall afterwards see, by no means the main one.

On seeking further to elucidate the problem, it becomes apparent that in all probability it is not the births themselves which could have this seasonal or other influence brought to bear upon them, but rather the conceptions from which the births result. If the birth curve be shifted back nine months (so that October numbers are in January), a corresponding curve—in character—is produced. This is now not the "birth curve," but the "conception curve."

And now at the onset we can dismiss the birth curve from the question. It is the "conception curve," which we shall afterwards prove is subject to seasonal and other influences; whose effects, however, only become apparent by the increased number of births.

"*The Conception Curve*" (Chart I.)

From January to February the curve falls, there being not so many conceptions. It then rises through March and April, falls in May, rising through June to its maximum in July. It falls again through August, September, to November, rising through December, January, and so on.

Now, what can cause this?

One is struck by the fact that the number of conceptions is greater in the hot than in the cold months. The effect of temperature becomes more evident when the "Temperature Chart" (Chart I.) is referred to.

It is then seen that when the temperature rises the number of conceptions increases, and that the temperature reaches a maximum in July, in which month the number of conceptions is also greatest. The temperature and conception curves then sink together to a minimum.

On referring carefully to this Chart, it will be seen that, although the two curves correspond in their principal features, in detail they do not always tally.

In the first place, a unit increase of temperature does not always produce a corresponding increase in the number of conceptions; thus, in the temperature curve, from August to September there is a fall of 4°, while the conception curve shows hardly any depression. Again, in three instances can be remarked a distinct deviation from the similarity. The number of conceptions in December and January increases, while the temperature slightly descends; and in May it descends while the temperature rises. It is seen then, that if the temperature curve is a factor—and we have not distinctly proved that yet—it is not the only one.

We shall afterwards find that the temperature and marriage curves are the great causes of the variations in the number of conceptions (with also other smaller factors).

Influence of Temperature Curve.

Although to the eye the temperature and conception curves so much agree, it is necessary to prove that the latter actually depends for its formation upon the former, and is not merely the result of some strange coincidence.

Having proved that, it will be necessary to formulate, as a law, the temperature influence, and to state arithmetically the influence of an increase of a temperature unit on the number of conceptions.

By means of "FOURIER'S Harmonic Analysis" we can analyse a curve into its harmonic constituents. The temperature and conception curves may be analysed into curves recurring respectively every twelve months, six months, four months, and so on. By this method the phase is given, and by comparing the two curves thus analysed the dependence can be seen (if any).

Thus, if it be found that there is one primary temperature curve (with maximum every twelve months), whose maximum falls exactly in the middle of the year; and that the conception numbers, when analysed, give just such a curve with a maximum at a corresponding phase, then the two correspond. They are due to the same cause, or one is the result of the other. In this case the conception curve would be the result of the temperature, not the temperature the result of the conceptions.

If, however, the maximum of one falls over the minimum of the other, there is certainly no direct relation.

On making such an analysis * it is seen that the temperature curve gives a well-marked primary wave.

If the time of one year be divided into 360 parts or degrees, then the maximum of this primary wave falls, at 185°, a little over the half year. The height or value of this curve may be represented by 10 units (see Mathematical Chart).

The secondary curve—namely, that one whose maximum recurs every six months—is well marked, but of not so great a value as the former. It may be represented by the number 2·3 as its value, with the maximum at +55°.

There are other curves of temperature which result from this analysis (Mathematical Chart); they are of shorter wave length, but their nature is not known—perhaps they result from errors of observation. Their value is small, and they may be discarded from this question. On making a similar analysis of the conception data one finds a primary wave with maximum at +183°, and with an altitude of 162·23 units. It is seen that the primary waves of the two curves correspond; the one—temperature—having its maximum at +185°, and the other—conception—at 183°. There is, then, not a difference of 1 per cent. between them, and for this we shall account hereafter. The two then undoubtedly correspond. The secondary conception curve has an altitude of 81·23, and the maximum fall at 53°.

It will be remembered that the corresponding wave of temperature was at 55°. These two again undoubtedly correspond, and the dependence is made yet more apparent when we see that the primary and secondary conception waves were just 2° behind (in point of time) the corresponding temperature ones.

There will also be seen other conception curves of yet shorter wave length on reference to Table.

	Temperature.		*Conception.*	
	Maximum at	Altitude.	Maximum at	Altitude.
No. 1 =	+ 185°	10	+ 183°	162·23
No. 2 =	+ 55°	2·3	+ 55°	81·23
No. 3 =	+ 27°	0·0	− 52°	9·0
No. 4 =	− 5°	1·0	− 37°	33·4
No. 5 =	+ 225°	0·0	+ 112°	17·0

Nos. 1–5 are primary, secondary, tertiary, &c., waves of temperature and conception, by FOURIER's Harmonic Analysis. (See Mathematical Chart for details.)

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* For a complete account of this method consult THOMSON and TAIT's "Natural Philosophy."

Having shown that the conception variations are produced chiefly by changes in temperature, it is necessary to determine more definitely the influence, and to find out the percentage increase which would follow an elevation of 1° (Fahr.) or unit of temperature.

By calculating from the original numbers in the register books, or still better, perhaps, by comparing the altitudes in FOURIER'S curves, it will be seen that an elevation of 1° (Fahr.) causes an increase of about ·5 per cent.

This can readily be done from the FOURIER curves. The altitude of the primary temperature curve is 10 units above the mean, while the altitude of the corresponding conception curve is 162 units. Therefore 1 unit is the cause (or corresponds to) 16·2 of conception.

To arrive at the percentage, find out the average mean number of monthly conceptions, which is 3127. Therefore 1° or unit causes an increase of 16·2 conceptions over the mean of 3127, or ·51 per cent. This may be taken roughly at ·5 per cent., it being absurd to state such a law very exactly where so many slight fallacies exist, from false registration and otherwise.

The influence of temperature on conceptions may be stated as a physiological law as follows :—

"Temperature is the main factor regulating the variations in the number of conceptions (and consequently of births) which occur during the year. It increases their number with its elevation, and this on an average of ·5 per cent. for an elevation of 1° Fahr. (in Scotland)."

It would be interesting to know what produces the secondary and other waves of temperature given by FOURIER'S analysis.

May it not be, that the one with a maximum in spring and autumn (the secondary curve) is caused by the local winds which then occur, and which no doubt greatly influence local temperature, being probably the great cause of its local variation (these themselves, of course, being primarily due to temperature)?

Marriage Factor.

By examining Chart II. or the following figures, it will be seen that in January the number of marriages contracted is very high. The numbers fall through February to March, rising in April only to fall again in May. From May, the month in which fewest marriages occur, the numbers suddenly rise to their highest maximum in June; falling through July, August, September to October, rising again in November, and falling slightly in December.

Average Marriage Curve of Years (1866–1875) *inclusive.*

January, = 1245
February, = 611

March, = 566
April, = 634
May, = 473
June, = 1430
July, = 1097
August, = 664
September, = 664
October, = 649
November, = 933
December, = 919

It is, in short, a curve with two maxima; one occurring in November, December, and January, and the other in June and July.

We shall now endeavour to investigate its influence upon the conception curve. Influence it must have,—the interesting point is the average interval between marriage and conception.

The best plan—having found out that temperature is a factor—is to subtract from the conception curve the temperature influence, and to study the resulting figures or curve which may be formed from them in connection with the marriage curve.

Find out the monthly average temperature, and in relation to this average express the other monthly numbers as + or − quantities. For example, the average monthly temperature is 47·1, and in January it is 38·5; therefore January will be 38·5 − 47·1 = − 8·6 (see Col. I.).

Do this for all the periods in the temperature and conception curves (see Cols. I. and III.).

Now add up all the minus quantities of both columns, and divide the resulting conception by the temperature numbers, which will give 18.

Multiply the numbers in the temperature column (Col. I.) by this number 18, which will give Column II.

Now that the temperature curve is so multiplied, it can be subtracted from the conception curve; this gives Column IV., which is the resulting conception curve from which all temperature has been subtracted.

	Col. I.		Col. II.		Col. III.	Col. III.
January,	= − 8·6	× 18 =	− 155	subtracted from	− 55 =	+ 100
February,	= − 7·4	„	− 133	„ „	− 126	+ 7
March,	= − 6·3	„	− 113	„ „	− 77	+ 36
April,	= − 1·0	„	− 18	„ „	+ 27	+ 45
May,	= + 2·1	„	+ 238	„ „	− 70	− 108
June,	= + 8·6	„	+ 155	„ „	+ 110	− 55
July,	= + 11·9	„	+ 214	„ „	+ 260	+ 46
August,	= + 10·7	„	+ 193	„ „	+ 163	− 30

		Col. I.		Col. II.		Col. III.	Col. IV.
September,	=	+ 6·4	× 18 =	+ 115	subtracted from	+ 162	+ 47
October,	=	0·0	„	0	„ „	− 20	− 20
November,	=	− 7·1	„	− 128	„ „	− 212	− 84
December,	=	− 8·7	„	− 156	„ „	− 148	+ 8

Col. I. = Temperature numbers treated as + and − quantities.
Col. II. = The above × by 18.
Col. III. = Conception curve treated as + and − quantities.
Col. IV. = Resultant conception numbers after temperature numbers in Col. II. have been subtracted.

When it is plotted as a curve it can better be studied (Chart III.).

It is difficult to see the dependence of the resulting conception curve upon the above marriage curve, although in some particulars they do agree.

It was only by taking into account other sets of data and other facts, that it was possible to prune from this conception curve parts which depended upon yet other factors, the resultant (completed in the above curve by the dotted lines) agrees most conclusively with the marriage curve. On examining the conception curve in this Chart, a large crest is seen in the months of June, July, August, September, and October,—broken, however, in August, another in March and April, and a third sharp peak in January.

After careful comparison with curves produced from other sets of data, it was found possible to completely explain all discrepancies between this and the marriage curve.

If the illegitimate births be examined (on which the marriage numbers can have no influence), a large maximum is always seen in October, corresponding to a maximum of conceptions in January. This results from the license which always exists in Scotland at the time of the New Year. That this license is great, every medical man will allow; and it is quite capable of producing a sharp rise of the conception curve.

Now this maximum in January may be discarded, and this leaves us a curve with only two maxima, which can be much better compared with the marriage curve.

There is yet a curious discrepancy in the curve, namely, the sudden dip of the curve in August, in the very middle, in fact, of a well pronounced crest.

This really does not exist in the curve of a whole country; but is probably due to a fluctuation—local in character—in the number of inhabitants.

On looking over the numbers, not of the eight towns of Scotland alone, but of all Scotland, August was seen to give not a fall, but a rise (see dotted line in Chart III.).

This dip in August does then not exist in Scotland, only in the towns. In all probability it is due to the outflux of inhabitants from the towns into the country at that season.

A dotted line in Chart represents what would occur were the population stationary. It is now seen that when these two disturbing factors are discarded, that the two curves present a most striking contrast. There are two maxima in each.

The smaller marriage maximum in December and January is followed by the smaller conception maximum in about two months,—this can be seen from this Chart, but will be proved from FOURIER's curves.

The larger marriage crest in June and July is followed in the same interval by the larger conception crest.

It will be seen that directly after a marriage rise a conception increase also takes place, thus the rise from May to June in the marriages is followed directly by a rise in the conceptions. This is as might be expected; they go on increasing until a maximum is reached in the second month, when most occur. The numbers then diminish, falling to a minimum.

By FOURIER's curves the interval between marriage and time of maximum of conceptions is almost exactly two months.

This point, which is of some interest from both a physiological and statistical view, is brought out, namely, that most conceptions do not take place for some time after marriage,—not until, in fact, after an interval of two months; and that therefore most children are born eleven months after marriage.

This has been already variously stated, and the interval quoted varies from 10·5 (SADLER) to 17 (M. DUNCAN) months.

For the results here given it may be claimed that by far the largest data ever used were brought to bear upon the subject (not being a mere tabulation of cases); and that the use of FOURIER's analysis gives an exactitude not otherwise attainable.

Yet another point may be mentioned: by comparing the altitudes of the curves, it will be seen that an increase of 100 marriages on the average produces an increase of sixty-four conceptions within a period of five months.

Stated otherwise, sixty-four per cent. of newly-married women have a child within a period of fourteen months.

This latter fact must, however, be received with a certain caution, as the first births are mixed up with the second, third, and so on; and although the first births will give the chief character to the curve, and the phase will not be vitiated, yet the altitude cannot be taken as quite correct.

From these curves a very important series of investigations can be made. The "duration of pregnancy" can be arrived at, a result thought before impossible; and also the interval between "insemination" and "conception."

The results which are before the Society to-night must not on this point be considered final, merely the "method of inquiry" will be indicated, and its application to the above curves will be made.

It is only by most careful working with different sets of data, and with more exact ones than those of Scotland, that a final decision can be arrived at upon so nice a point, where the difference of a day or two is everything.

When sufficient data are at hand, this matter will receive further attention.

Scientifically defined, the "duration of pregnancy" is the length of time which elapses between conception (not insemination) and delivery.

Now one knew nothing before about the time when conception occurs, and therefore nothing exact about the "duration of pregnancy."

Statistics tell us that the time between "insemination" and delivery is, on an average, 275 days. Now, however, by the temperature curve, we have an indication of when conception occurs.

All we have to do is to find out exactly how far we must put back the birth curve in order to get the primary and secondary curves—FOURIER—*exactly* to correspond to the similar curves; to do, in fact, *exactly* what we have already done roughly when we put the birth curve back nine months.

This interval is the "duration of pregnancy."

When analysed it will be remembered that the primary curve maximum was at 183° and the secondary at 53°; while the corresponding temperature curves give 185° and 55°.

The difference in both cases is therefore 2°. They show therefore conclusively that the birth curve has been put back 2°, or $\frac{2}{360}$th of a year, or a little more than two days too much.

To make them agree exactly, it should have been put back 175° or 272 days. This 272 days elapses between conception as indicated by temperature curve, and delivery as given in the Register-General Reports. This 272 days is the duration of pregnancy. Now, it is already known that the average interval between insemination and delivery is 275 days; therefore $275 - 272 = 3$ days is the time which elapses between insemination and conception.

These facts, important in their physiological bearings, enable us to construct a complete table, showing the intervals between all the physiological processes concerned in the birth of a child.

We have the time between

Last menstruation and delivery = 278 days (MATT. DUNCAN);
Insemination and delivery = 275 days (MATT. DUNCAN);
Conception and delivery = 272 days.

Insemination (which is to be followed by conception) then occurs three days on the average after last menstruations; conception follows this in three more days; and delivery in 272 days.

It may be asked, What right have we to say that the influence of temperature is on conceptions and not on insemination?

The answer is not difficult, for the interval between coition and delivery is greater (275 days) than our interval (272 days) between conception and delivery. The coition would therefore fall behind the temperature curve, therefore not affected by it. No doubt there may be some influence on the number of coitions, but this influence is not great enough to be shown.

Law of Capacity of Conceiving.

The facts that we have gleaned about the influence of temperature upon conception, enable us fully to state as a law the capacity of conceiving of women during different periods of their life.

There are three factors which are to be considered as modifying this capacity, namely,

(I.) Time of Life.
(II.) Temperature.
(III.) Menstrual Rhythm.

(I.) *Time of Life.* (For particulars consult "Fertility, Fecundity, and Sterility," by Dr MATTHEWS DUNCAN.)

This influence effects woman's capacity in that the sexual organs are only gradually developed as age advances; at a certain period they are developed fully, and then undergo a gradual involution.

At birth the capacity is nothing; it remains so until puberty, when capacity first appears.

This increases with age until between twenty and twenty-four, when the maximum is reached. The capacity then weakens until about the fortieth or forty-fifth year, when it becomes, as at birth, nothing.

This will be seen better on referring to the following curve (Chart IV.).

This curve is however modified by the other factors; and the result, given when all the factors are considered, gives a curve such as is represented in the figure, where one year of the previous curve is depicted with the other ones superimposed (Chart V.).

(II.) *The Effect of the Temperature Curve* is to give a maximum every summer, giving the age curve (Chart V.) a wavy appearance, with a crest and trough every year.

How this temperature influence is exerted will be considered hereafter.

(III.) *The Menstrual Rhythm* occurs twelve times in the year, and gives twelve maxima to Chart (V). About its influence little is known, whether a successful coition may always occur, or only at a certain period in connection with this rhythm, is uncertain. It appears, however, that about six days after menstruation most conceptions occur.

The capacity of conceiving in a woman is then strongest (I.) between the ages of twenty and twenty-four; (II.) in the hottest season of the year; and (III.) about six days after menstruation.

In conclusion, a few words may be said as to the mode in which temperature effects conceptions.

Certainly not, as has been suggested, by raising the temperature of the body and of the uterine mucous membrane, giving thereby, as was supposed, more favourable surroundings to the sperms or ova.

It is certain that a temperature about that of the body is most favourable to the life of ova and sperms; but the difference of a few degrees would be very immaterial, the latter (the spermatozoa) living for many hours in active movement at the ordinary temperature of the air.

Then again the difference in warmth of the interior of the human body varies little in the year. There is hardly a perceptable difference between the temperature in depth of winter or height of summer.

It may be received as a fact, that there are external agencies, such as cold, heat, rain, wind, &c., which are, under certain conditions, antagonistic to life, and, when in action, they affect *all of us.*

On the weak a force which will produce an overpowering result which we call death, will on the strongest have its effect, may be, only producing a slight depression of the natural energy. So that a district which has a high mortality is bad for the strongest, and a season which has a high mortality is also dangerous to all.

Now, if the "death curve" be plotted in the same way as the "conception curve," it will be seen to be an *inverted* temperature curve in the main. As the temperature rises, the gross number of deaths diminishes.

From our maxim, then, an increase of temperature is favourable to the health of all. The "health curve," could we delineate such a thing, would, with the conception curve, correspond mainly with the temperature curve. Indeed, the increased capacity of conception is, we imagine, only an indication of an increased energy of the whole body, in which this function naturally shares.

We must here remember that the power of producing offspring is a function which perhaps of all others is most taxing to strength, and therefore depends much upon physical tonus.

A very rapid glance at the influence of temperature upon the power of reproduction in the lower animals, may not be out of place. With those of very low organisation, Bacteria, Vibriones, and all organic ferments, a certain temperature is absolutely necessary to their development.

As we pass up the invertebrate animal kingdom, we find in every class *seasons* of reproduction. In the vertebrata we have spawning seasons for the fishes; amphibians, reptiles, birds, and mammals have all their breeding seasons. We might note here many curious zoological facts connected with the seasonal development of sexual organs, if the subject of the paper permitted. In the foregoing examples the temperature no doubt mainly operates through the vegetable world, varying the amount and quality of food at different times. Thus few animals breed in winter, when food is scarce and their bodily powers are at a low ebb.

Amongst civilised men and domestic animals the variations in the amount of food are brought to a minimum, and as a consequence conceptions can occur all the year round, mostly, however, in summer.

A dog can have pups in every season of the year; his food is ensured to him, and he is never reduced to extremes of hunger, as are his antecedents the wolf and the fox, who almost never have young in winter.

Here we have an instance of how temperature influence can be ameliorated by more favourable circumstances. Amongst savage tribes of men, living in rigorous climes, the conception curve probably is more marked than in Scotland.

We see therefore that temperature is a great—the greatest—factor modifying life. It modifies the number of children born; it is connected, directly or indirectly, with almost every disease that is known; and therefore becomes a chief factor in producing the retrogressive change which we call death.

In conclusion, I wish to express how much I am indebted to Professor TAIT, not only for having directed my attention to and explained to me the mode of applying FOURIER'S formula to this investigation, but for having checked the results. Without his aid I could not have carried out the investigation.

Temperature and Conception Numbers by Fourier's Harmonic Analysis.

The formula is

$$f(t) = A_0 + A_1 \cos t + A_2 \cos 2t + \ldots + A_6 \cos 6t$$
$$+ B_1 \sin t + B_2 \sin 2t + \ldots + B_6 \sin 6t.$$

But, by the form of the data, we have always $B_6 = 0$.

[Original Averaged Numbers from Registrar-General's Reports seen on left hand of Chart. Passing from left to right the steps are given by which the α's and β's are finally deduced.

Series (*a*) is the Temperature, (*b*) the Conception set of figures.]

(*a*)

(1) January, = 38·5
(2) February, = 39·7
(3) March, = 40·8
(4) April, = 46·1
(5) May, = 49·2
(6) June, = 55·7
(7) July, = 59·0
(8) August, = 57·8
(9) September, = 53·5
(10) October, = 47·1
(11) November, = 40·0
(12) December, = 38·4

(*b*)

(1) January, = 3072
(2) February, = 3001
(3) March, = 3050
(4) April, = 3154
(5) May, = 3057
(6) June, = 3227
(7) July, = 3387
(8) August, = 3290
(9) September, = 3289
(10) October, = 3107
(11) November, = 2915
(12) December, = 2979

By Formula.

$A_0 = \frac{1}{12}$ of whole sum of 1–12,

$$A_1 = \tfrac{1}{12}\left(\frac{1^*}{1} + 3 - 5 - \frac{7}{7} - 9 + 11 + \sqrt{3}(2 - 6 - 3 + 12)\right)$$
$$A_2 = \tfrac{1}{12}\left(\frac{1}{1} + 2 - 3 - \frac{4}{4} - 5 + 6 + \frac{7}{7} + 8 - 9 - \frac{10}{10} - 11 + 12\right)$$
$$A_3 = \tfrac{1}{12}\left(\frac{1}{1} - \frac{3}{3} + \frac{5}{5} - \frac{7}{7} + \frac{9}{9} - \frac{11}{11}\right)$$
$$A_4 = \tfrac{1}{12}\left(\frac{1}{1} - 2 - 3 + \frac{4}{4} - 5 - 6 + \frac{7}{7} - 8 - 9 + \frac{10}{10} - 11 - 12\right)$$
$$A_5 = \tfrac{1}{12}\left(\frac{1}{1} + 3 - 5 - \frac{7}{7} - 9 + 11 - \sqrt{3}(2 - 6 - 3 + 12)\right)$$
$$A_6 = \tfrac{1}{12}(1 + 2 + 3 - 4 + 5 - 6 + 7 - 8 + 9 - 10 + 11 - 12)$$

and

$$B_1 = \tfrac{1}{12}\left(2 + \frac{4}{4} + 6 - 8 - \frac{10}{10} - 12 + \sqrt{3}(3 + 5 - 9 - 11)\right)$$
$$B_2 = \tfrac{1}{12}(2 + 3 - 5 - 6 + 8 + 9 - 11 - 12)\sqrt{3}$$
$$B_3 = \tfrac{1}{6}(2 - 4 + 6 - 8 + 10 - 12)$$
$$B_4 = \tfrac{1}{12}(2 - 3 + 5 - 6 + 8 - 9 + 11 - 12)\sqrt{3}$$
$$B_5 = \tfrac{1}{12}\left(2 + \frac{4}{4} + 6 - 8 - \frac{10}{10} - 12 - \sqrt{3}(3 + 5 - 9 - 11)\right)$$

Are given as follows.

$A_1 = -\ 10$
$A_2 = +\ 1·3$
$A_3 = +\ 0·06$
$A_4 = +\ 1·27$
$A_5 = +\ 0·3$

$B_1 = -\ 0·9$
$B_2 = +\ 1·9$
$B_3 = +\ ·03$
$B_4 = -\ ·1$
$B_5 = -\ ·3$

$A_1 = -161·7$
$A_2 = +\ 48·5$
$A_3 = +\ 11$
$A_4 = +\ 52·6$
$A_5 = -\ 6·8$

$B_1 = -\ 9·56$
$B_2 = +\ 65·2$
$B_3 = -\ 14·6$
$B_4 = -\ 40·6$
$B_5 = +\ 18·4$

By formula. $\alpha_1^2 = A_1^2 + B_1^2$.

$\alpha_1 = 10$
$\alpha_2 = 2·3$
$\alpha_3 = \ldots$
$\alpha_4 = 1·0$
$\alpha_5 = \ldots$

$\alpha_1 = 162·3$
$\alpha_2 = 81·23$
$\alpha_3 = 9·0$
$\alpha_4 = 33·4$
$\alpha_5 = 17·0$

By formula. $\tan B_1 = \frac{B_1}{A_1}$

$\beta_1 = +\ 185°$
$\beta_2 = +\ 55°$
$\beta_3 = +\ 27°$
$\beta_4 = -\ 5°$
$\beta_5 = +\ 22°$

$\beta_1 = +\ 183°$
$\beta_2 = +\ 53°$
$\beta_3 = -\ 52°$
$\beta_4 = -\ 37$
$\beta_5 = +\ 112$

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* Any number taken twice over when placed so:— $\frac{1}{1}$ or $\frac{2}{2}$.

EXPLANATION OF CHARTS.

CHART I.

Conception Curve—dark line. The actual numbers are given on left-hand side. The Temperature Curve represented by a dotted line. The numbers are omitted. (See pp. 2, 3.)

CHART II.

Marriage Curve placed for sake of contrast just underneath the Conception and Temperature Curves. The numbers are on left-hand side. (See pp. 2, 5.)

CHART III.

Shows Conception Curve after Temperature factor has been subtracted. .... line shows the real course of Curve (see p. 7). Below is Marriage Curve. (See pp. 6, 7.)

CHART IV.

Shows the capacity for conceiving at different ages of women. The numbers are years of age. (See p. 10.)

CHART V.

Shows all the factors influencing the conceiving power of a woman, taken for a single year (say 20–21).

(A) Represents Age Curve, and rises in Chart, being that of a single year from 20–21. (See pp. 10, 11.)

(B) Temperature Curve, rising every year in summer.

(C) Curve representing Menstrual Rhythm, occurring twelve times in the year.

V.—*On the Physiological Actions of Drugs on the Secretion of Bile.* By William Rutherford, M.D., F.R.SS. L. and E., Professor of the Institutes of Medicine in the University of Edinburgh.

From Experiments performed with the assistance of Monsieur W. Vignal and William J. Dodds, M.B., D.Sc.

(Read on 5th March 1877 and on 17th June 1878. Abstracts in the "Proceedings" of those dates.)*

INTRODUCTION.

(*For References and Table of Contents, see end of Memoir.*)

Since the liver is an organ whose due activity is indispensable for the maintenance of health; since it is frequently the subject of disorder, and consequently receives a large share of attention from the physician, it is obviously of great importance that he should possess precise knowledge of the manner in which it is affected by medicinal agents.

The physician has had no difficulty in determining when a substance excites the sweat glands, the salivary glands, or the kidneys, but as regards the liver he has been so much embarrassed, that although substances supposed to increase the discharge of bile (cholagogues, *χολη*, bile; *αγω*, to drive away) have been administered to man for over 2000 years, there has always been much uncertainty as to those which are really to be regarded as cholagogues; and even in the case of any agent which increases the discharge of bile, he has been quite unable to determine whether this effect is due to a stimulation of the *bile-secreting* or of the *bile-expelling* mechanism.

The reasons for these uncertainties are not difficult to find. The bile, when it enters the intestinal canal, mingles with other secretions, and with alimentary substances, whose quantities are variable. The physician roughly estimates the amount of bile discharged, by observing the colour of the dejections—a method which is of necessity so inaccurate that it is often difficult, sometimes indeed impossible, to say whether or not the discharge of bile is increased, diminished,

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* By the permission of the Council, I have been allowed a year to prepare this research for publication in the "Transactions." The experimental work was, however, entirely completed before the last abstract was read before the Society.

or unchanged. Thus, when rhubarb is administered, it gives a colour to the dejections similar to that communicated by the bile, and the physician is therefore puzzled to say whether or not rhubarb affects the liver; yet, by another method of research, it can be shown that rhubarb increases the secretion of bile. Where the substance, as in the case of sodium sulphate, stimulates the intestinal glands, and thus occasions copious dejections of a watery character, whereby their colour is diluted, the physician has found it difficult to say whether or not there is a variation in the quantity of bile discharged; yet by another method, it can be shown that this substance certainly stimulates the liver as well as the intestinal glands. Again, in the case of such substances as magnesium sulphate and castor oil, which stimulate the intestinal glands but not the liver, the physician, although he certainly did not suppose that they increase the flow of bile, nevertheless failed to observe the fact—which may be shown by another method,—that *they diminish the production of bile.* Again, when a substance excites the liver to produce more bile, but does not excite the intestinal glands to pour forth their watery secretion, and as it were wash out the bile discharged into the canal, the clinical observer has in the case of benzoic acid and its compounds, sodium salicylate, and others, failed to observe that they are cholagogues. But again, the clinical observer is unable to say whether or not any cholagogue actually stimulates the hepatic cells to produce more bile, or merely excites the muscular fibres of the gall-bladder and bile ducts to expel their contents. Yet rational medicine imperatively requires that the first of these questions at all events shall receive a definite answer.

There are two methods—the clinical and the physiological—by which the actions of medicinal agents are investigated. On the clinical method, experiments are made on men and animals in a state of disease, with a view to cure the diseased condition; whereas, on the physiological method, experiments are made with drugs on animals and sometimes also on man in a state of health, with a view to determine how they affect the bodily system when its action is not distorted by the influence of disease. The clinical method is as old as medicine itself, but the physiological mode is of comparatively recent date, and has grown out of the fact that the clinical method has proved to have very seriously failed—and nowhere more signally than in the case of the liver—to furnish the physician with that definite knowledge which is required to bring therapeutics even within sight of the pale of exact science.

Of necessity the influence of a drug upon a diseased condition is the ultimatum of pharmacology, and every experiment upon a healthy bodily system, whether of man or animal, is merely ancillary to experiments with the drug in disease. Therefore, if we discover that a drug stimulates the healthy liver of such an animal as a dog, we do not infer that it must also stimulate the human liver in health, and still less do we conclude that it must also act thus in disease. The experiments on the healthy liver of the dog, on the normal, and on the abnormal human liver, are *three sets of experiments* closely related, but still distinct. The facts derived from any one of the three cannot be substituted for those of the other two. Each set of facts has its own proper place, and must be carefully kept there. When, therefore, we show by the physiological method that such substances as sodium benzoate, sodium salicylate, ammonium phosphate, and others, powerfully stimulate the liver of a dog, we do not for a moment say to the clinical observer, you will find that these things have a similar action in man. We merely say it is likely that they also act thus in man; experiment with them in his case, and tell us if you find that they have on him a similar action, and tell us also in what diseased states you find the employment of this or of that substance most advantageous.

All are agreed that medical science has much to gain from the attainment of a precise knowledge of the physiological actions of medicinal agents. The action of ipecacuan in dysentery is an apt illustration of this fact. On asking a highly experienced Indian physician how he explained the appearance of a large amount of bile in the dejections after the administration of sixty grains of ipecacuan in cases of dysentery, he at once replied, "My theory is that it relieves a spasm of the bile ducts, and thus allows of the escape of pent-up bile." But, when we give sixty grains of ipecacuan to a healthy dog, it never fails to cause the liver to secrete a greatly increased quantity of bile. Probably, therefore, no one will now be inclined to doubt that in dysentery, ipecacuan affects the liver in a similar manner, and that the increased discharge of bile is due to its increased secretion, and not to the relief of an imaginary spasm of the bile ducts. It must be admitted that the attainment of this precise knowledge regarding the action of ipecacuan does not reveal to us the true pathology of dysentery, but it places us one step nearer to a knowledge of it; for once we know the action of a drug in a healthy state of the body, and find that a diseased state is cured by that action, our knowledge of the nature of the diseased state is necessarily advanced.

While all have admitted the limited and unsatisfactory character of our knowledge of the effects of drugs on the liver, several investigators have attempted to advance the subject by the physiological method of experimenting with drugs on animals. Nearly all the observations have been made on the dog—that being the animal best suited for the purpose. The method resorted to by the earlier experimenters was that of continuously collecting the bile from a *permanent* biliary fistula, and observing how its amount and composition were affected by drugs. A permanent biliary fistula is established by occluding the common bile duct, and establishing a communication between the fundus of the gall-bladder and the exterior of the abdomen. When the wound in the abdominal wall has completely healed, and nothing remains but the fistulous opening into the gall-bladder, through which all the bile is necessarily discharged, a cannula is placed in the fistulous opening, and the bile collected either in a bag attached to the cannula, or in a large sponge placed in a tin box and secured to the abdomen of the animal. The difficulty of perfectly collecting the bile continuously by day and night, while allowing of such freedom of movement on the part of the animal as is necessary for the maintenance of its health, is so serious that few investigators have succeeded in accomplishing the task. By this method NASSE (1852, *Op.* i.) KÖLLIKER and MÜLLER (1855, *Op.* ii.), and SCOTT (*Op.* iv.), severally made observations on a single dog with reference to the effect of calomel on the biliary secretion, and the results of their experiments will be detailed under the action of mercury. Being in some measure contradictory, the subject was in 1866 taken up by a committee, of which the late Professor HUGHES BENNETT was chairman and reporter. Professor ARTHUR GAMGEE and the author were the two junior members of the committee upon whom devolved the task of performing the experiments. The investigation was laborious, and lasted two years. Very great difficulty was experienced in making a constant collection of the bile extending over a number of days, and it was repeatedly observed, that although the animals were kept on a fixed diet, remarkable variations took place in the amount of bile secreted daily, when no cause could be assigned.

This circumstance rendered the method of experiment one from which it was difficult to arrive at just conclusions; nevertheless the experiments seemed to warrant the statement that "spontaneous diarrhœa, dysentery, and purgation produced by pilula hydrargyri, calomel, corrosive sublimate, and podophyllin diminished the solid constituents of bile, and, with one exception, the fluid portion of the bile also" ("British Association Reports," 1868, p. 229).

These are indeed meagre results, considering the great labour which their attainment entailed, and it must be admitted that they were to some extent misleading; not because of any inaccuracy of observation, but because the method of experiment was not adapted to supply, at brief successive periods of time, information regarding the state of the secretion of bile. On that account it failed to show that in the case of such a substance as podophyllin—which certainly increases the biliary secretion, but which also stimulates the intestinal glands,—if too large a dose be given, the effect on the liver may be overcome by its effect on the intestine, and a diminished secretion of bile result. (See Experiment 9 in the sequel.)

In 1873 RÖHRIG (*Op.* vi.) reopened the investigation of this subject. He observed the rate of biliary flow from *temporary* fistulæ in fasting curarised dogs before and after the injection of purgative agents into the stomach or intestine. He found that large doses of croton oil greatly increased the secretion of bile, and that a similar effect, though to a less extent, was produced by colocynth, jalap, aloes, rhubarb and senna, and sulphate of magnesia—the potency of these agents as stimulants of the liver being in the order mentioned. He found, moreover, that castor oil had little effect, and that calomel, while it seldom recalled the biliary secretion after it had ceased, nevertheless somewhat augmented it when it was taking place slowly.

Röhrig's statement with regard to calomel does not much differ from that made by Hughes Bennett's committee, but nevertheless he did find that certain purgative agents, when given to *fasting* animals with temporary biliary fistulæ, increased the biliary secretion, while the committee found that in *non-fasting* animals with permanent fistulæ, purgative action, induced by podophyllin, calomel, &c., diminished the amount of bile secreted in the twenty-four hours.

It appeared to me that this important subject could not be allowed to remain in a position so unsatisfactory. I therefore entered on the following research, but ere I had proceeded very far I found its labours so excessive, that I was glad to avail myself of the very valuable assistance of my pupils, Monsieur W. Vignal, and latterly of Dr William Dodds, in performing the experiments.

Method of Experiment.

All the experiments recorded in the following pages were performed on dogs. The dog was selected—1. Because the size of its common bile duct renders it possible to introduce a cannula with an orifice sufficiently large to prevent its being blocked up by particles of inspissated mucus from the gall-bladder. 2. For the reason that its digestion resembles that of man, inasmuch as its stomach becomes empty when the process is completed. It is very different in the case of a rabbit, whose stomach is never empty. 3. As Röhrig had performed his experiments on dogs, it was necessary that we should compare our results with his. The selection of the dog has proved fortunate, for the results of our experiments are in complete harmony with every perfectly ascertained fact regarding the actions of medicinal agents on the human liver, and prove that the liver of this animal is affected in the same sense—although it may not be to the same degree—by substances that act on the human liver. All the experiments having been performed on animals of the same species placed as nearly as possible under similar conditions, the results are fairly comparable; although it must be borne in mind that just as no two members of the human species can even in their normal condition be regarded as equally susceptible to the influence of any medicinal agent, neither can any two members of the canine species be held to possess identical susceptibilities. All the animals had a full meal of lean meat at three or four o'clock in the afternoon, and the experiment was begun between nine and ten o'clock on the following morning, so that the digestion and absorption of the food were completed, and the animal was therefore in a fasting condition. This was an essential preliminary; for, as is well known, the secretion of bile is accelerated during the process of digestion, and had we taken the amount of bile secreted per hour during digestion, as an index of the activity of the liver, previous to the administration of a drug, our experiments would necessarily have been worthless. The disturbing effect of irregular muscular movements upon the biliary flow was prevented by injecting into a vein small doses of curara, repeated at intervals, when the motor paralysis which it induces became too slight. In consequence of the curara palsy, artificial respiration was had recourse to, and maintained at regular intervals throughout the whole experiment. Chloroform was used during the preliminary operation in two cases, but the stimulation of the liver which it induced rendered the experiments worthless.* On the other hand, we have abundantly proved that the doses of curara administered in the following experiments have no influence on the biliary secretion, and do not interfere with the effects of hepatic stimulants. It is, therefore, an exceedingly valuable auxiliary in a research of this nature. The method of experiment we adopted was always that of a *temporary* biliary fistula. Through an opening in the linea alba a glass cannula was inserted into the common bile duct near to its junction with the duodenum, and tied therein. To the end of the cannula projecting from the abdomen a short caoutchouc tube was attached, and to the free end of this a short glass tube drawn to a narrow aperture so that the bile might drop from it, as Röhrig (*Op.* vi.) had recommended. The gall-bladder was then compressed, in order to fill the whole tubing with bile, and the cystic duct was clamped to prevent its return to the gall-bladder, and so compel all the bile secreted by the liver to flow through the cannula. The wound in the abdominal wall was then carefully closed, and in all save the earliest experiments the animal was thoroughly covered with cotton wool, in order to quickly restore it to its normal temperature; and guided by a thermometer in the abdominal cavity, great care was taken to keep the temperature normal,—a matter of no small importance,—for if the temperature fall several degrees, the liver secretes more slowly.

The respiration requires to be maintained with regularity, otherwise the

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* It may be well to state, however, that in all the operations for the previous experiments on the action of cholagogues performed by Dr Rutherford twelve years ago, at a time when there was no antiphysiological excitement prevailing, chloroform was fully administered to every animal, because in those experiments the biliary fistula was of a permanent nature, and observations were not begun on the biliary secretion until some days after the operation—when of course the effect of the chloroform had completely passed off. The biliary fistula being of a temporary character in the present research, and the whole time taken up by each experiment being not more than a few hours, the use of anæsthetics was inadmissible.

biliary flow is rendered somewhat unequal by irregular diaphragmatic compression of the liver. Moreover, if the respiration be deficient, the secretion of bile is always diminished. Some of the slight oscillations observable in the charts of the biliary secretion in these experiments are probably owing to variations in the respiration; for in the earlier experiments we were obliged to have the respiratory bellows moved by the hand, and this is never so regular as a machine. Notwithstanding this, however, the main results of these experiments are perfectly clear.

Until it is attempted, one might suppose that this mode of experiment is extremely simple, but it is by no means so simple as it appears. It is needful to manipulate the abdominal viscera with great care, and to avoid all dragging at the bile-duct, otherwise the secretion of bile becomes so irregular that the experiment may be useless. The cannula must be very carefully retained in a position which will permit of its moving with the diaphragm, but will prevent it from twisting the duct, and thus impeding the exit of the bile by forming a valve at its orifice.

Röhrig estimated the velocity of the biliary secretion by counting the seconds that elapsed between the fall of the drops from the orifice of the tube. A single trial convinced us that this method is extremely laborious, and leads to inaccurate results, because it does not permit of continuous observation for any length of time. Variations in secretion often occur independently of the administration of any substance, and it is impossible to estimate their significance, and make due allowance for them, unless the method of continuous collection of the bile be adopted. Moreover, we saw that the degree of viscosity of the bile caused a variation in the size of the drops, and, therefore, in the intervals between their fall. We therefore abandoned this for the more accurate method of allowing the bile to flow into a fine cubic centimetre measure, and recording the quantity secreted every quarter of an hour. In addition to constant collection of the bile, this method has the great advantage of permitting a graphic representation of the results.

It is evident from the method of experiment that all our observations relate exclusively to the effects of substances on the *bile-secreting* mechanism. We have made no observations regarding their effects on the *bile-expelling* mechanism. Nor do we intend to prosecute the latter part of the inquiry, for the question, what substances stimulate the liver to secrete more bile, is of infinitely greater importance. We shall be able to give to it a precise answer, and thus for the first time to furnish the physician with definite knowledge for his guidance in the treatment of hepatic disorder.

In several instances we analysed the bile secreted before and after the administration of a drug, but although valuable facts were thus ascertained, we found that in consequence of the excessive labour of this research it was impossible to analyse the bile in all cases. We therefore discontinued the analyses, after observing that even when a hepatic stimulant renders the bile more watery, the increased velocity of secretion always more than compensates the diminution of the solids, and thus compels the liver to produce in a given time a larger amount of the biliary constituents proper.

We were also at the pains to make in most cases *post-mortem* examinations of the small and sometimes of the large intestines and stomach, in order to compare the effect of the drug on the liver with its effect on the intestine. The results are valuable, because—1. They furnish for the first time a systematic account of the effects of well-known and also of many new drugs upon the intestinal mucous membrane; 2. By separating the secretion of the liver from that of the intestinal glands, a more exact knowledge of the effects of substances on the latter is obtained, and a very important generalisation regarding the effect on the secretion of the bile, produced by stimulating the intestinal glands, has been arrived at, as will be shown in the sequel. It ought to be observed that some of the substances might perhaps stimulate the pancreas, and as the pancreatic duct was never tied, the fluid in the intestinal canal may have been a mixture of intestinal and pancreatic juices. But as the liver was the primary object of our investigations, it would have been altogether unjustifiable to have set up more irritation at the duodenum, by cutting down on the pancreatic duct and placing a cannula in it—always a difficult thing to do in the dog, and apt to involve a good deal of hæmorrhage. Although by such a procedure, definite knowledge might have been arrived at with regard to what substances affect the pancreas, yet our results as regards the liver—a gland of greater importance—in the economy, might have been vitiated. Probably in most cases the fluid found in the intestine was chiefly intestinal juice, but for the reason mentioned no conclusive statement is permissible with regard to this point.

The small doses of curara given to the animals were injected into the jugular vein, in order that their effect might be speedy; but nearly all the drugs given for the purpose of affecting the liver or intestine were injected into the duodenum, because the animals being curarised could not swallow, and the penetration of the duodenal wall by the sharp nozzle of a small syringe was a much simpler operation than the introduction of a tube down the œsophagus into the stomach. Moreover, the stomach in a dog that has fasted for many hours usually contains a large quantity of mucus that must have retarded the absorption of the substance if given by the mouth. To avoid this delay was a matter of great importance, both on the animal's account, and also because of the impossibility of continuing the experiment for more than a few hours. Moreover, it has been alleged that the action of a cholagogue may be due to a reflex excitement of the liver proceeding from the duodenal mucous membrane; therefore by always injecting the substances into the duodenum we ensured its action—if any—on this portion of the intestine. It must of course be borne in mind, that when a drug is placed in the duodenum directly, and a certain effect on the liver ensues, it by no means follows that the same effect will accrue, if the drug be placed in the stomach and thus come in contact with the gastric juice. But the general harmony of the results of our injecting substances into the duodenum, with those observed in man when the drugs are taken by the mouth, convinces us that our method is reliable. In only one instance indeed—that of calomel—did it seem probable that its having escaped the influence of the gastric juice was vitiating the result, for the hydrochloric acid of the juice can convert calomel into corrosive sublimate, and we have discovered that while calomel does not, corrosive sublimate does stimulate the liver. A discussion of that case will be found under the action of mercury, and we think it the only one that needs special consideration.

SECRETION OF BILE IN A CURARISED FASTING DOG.

It was of course necessary—as a preliminary step—to observe the amount of bile secreted in the course of a day by a dog that had fasted about eighteen hours, and to which nothing but curara was administered. The solution of curara employed in all the experiments was a filtered aqueous solution, every minim of which contained one milligramme of the poison. The solution was always injected into the jugular vein.

In all the woodcuts the numbers under the abscissa indicate the hours during which the secretion of bile was observed, while those to the left of the ordinate indicate in cubic centimetres the amount of bile which flowed from the cannula; the dots in the curve indicate the quantities of bile collected every quarter of an hour. The vertical dotted lines that cross the curves in the illustrations indicate that something was given to the animal. In all such experiments the amount of bile first collected is usually considerably larger than that at subsequent periods. This apparently results from the sudden diminution in the resistance to the exit of the bile consequent upon opening the duct. The first one or two collections are therefore not reliable indices of secretion, and they are consequently omitted from some of the charts.

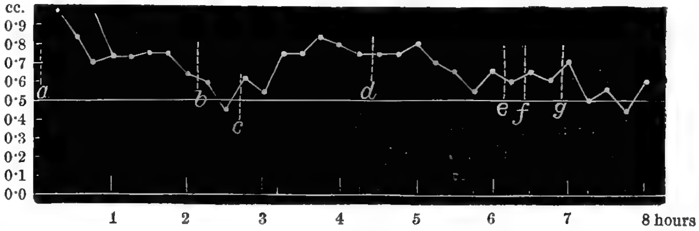

Fig. 1.—Secretion of bile by a fasting dog with nothing but curara administered. *a*, 20 mill.; *b*, 2 mill.; *c* and *d*, 4 mill.; *e*, *f*, *g*, 3 mill. curara injected into jugular vein.

Experiment 1. Dog that had fasted eighteen hours. Weight 7·6 kilogrammes. —Twenty milligrammes of curara were injected into jugular vein (at *a*, fig. 1). The abdomen was then opened, and the cannula placed in the common bile-duct, as above indicated. The wound in the abdomen was closed, the animal enveloped in cotton wadding, and the bile collected. As the experiment proceeded, the effect of the curara gradually wore off, owing to its elimination, and it was necessary to inject from two to four milligrammes from time to time (*b*, *c*, *d*, *e*, *f*, *g*, fig. 1). If the curve be examined, it will be observed that these doses had no apparent effect on the biliary secretion, which was in this case tolerably regular. After falling until the middle of the third hour, it increased for a time and then fell somewhat. At the eighth hour it was slightly below what it had been at the close of the first.

Experiment 2. Dog that had fasted seventeen hours. Weight 18·7 kilogrammes (fig. 2).

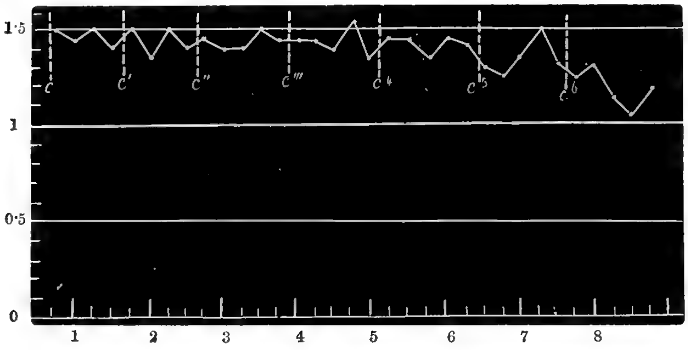

Fig. 2.—Section of bile by a fasting dog with nothing but curara administered. 20 mill. given at c ; 4 mill. given at c', c'', c''', c^4, c^5 ; 3 mill. given at c^6.

As it is evident from these two experiments that doses of curara such as those given above do not apparently affect the biliary secretion, the times at which they were given are not indicated in any of the subsequent charts, for in all cases curara was given as above indicated. The great value of this substance in this connection is, that while not obviously affecting biliary secretion, as chloroform does, it paralyses voluntary movement, and thus prevents the irregular outflow of the bile that ensues when the abdominal muscles contract.

The analysis of the bile in such a case as the above having been omitted, another experiment was performed for the purpose of supplying the want.

Experiment 3. Dog that had fasted nineteen hours. Weight 15 kilogrammes.—Nothing was given but curara in doses similar to those above-mentioned (fig. 3).

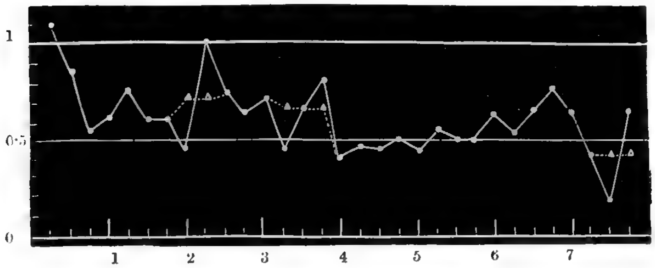

Fig. 3.—Secretion of bile in a fasting dog with nothing but curara administered.

The biliary flow was not so regular in this as in the previous cases. The mean has been taken, and triangles with dotted lines are superadded in fig. 3 for the purpose of indicating the probable position of the *dots* had the secretion been regular. This was done on the supposition—entertained until more experience was gained—that these irregularities in the curve were due, not to variation in *secretion*, but to irregularity of *outflow*, owing to a variation in the facility with which the bile could enter the cannula. It was in time ascertained, however, that an irregular curve generally ensued when there was much difficulty in inserting the cannula into the duct, and the latter had to be a good deal pulled about; in consequence of which the liver probably suffered somewhat from nervous irritation.

Composition of Bile in a Fasting Dog.

Analyses were made of the bile secreted by the third dog during the first, fourth, and last hours of the experiment.

The following are the results :—

TABLE I.—*Composition of Bile secreted by a Dog paralysed by Curara after fasting nineteen hours.*

Experiment 3.	Bile secreted during		
	First Hour.	Fourth Hour.	Last Hour.
Water, ...	89·53	89·58	89·55
Bile-acids, pigments, cholesterin, fats,	8·73	8·68	8·71
Mucus, ...	0·71	0·72	0·72
Ash, ...	1·03	1·02	1·02
Total, ...	100·00	100·00	100·00

It therefore appears that in the progress of the experiment the composition of the bile remained almost precisely the same. It should be mentioned that in taking the bile secreted near the beginning of such experiments for analysis, we were always careful to eliminate that which had been expressed from the gall-bladder into the cannula.

Secretion of Bile per Kilogramme of Body-weight in a Fasting Dog.

The absolute quantity of bile secreted by different individuals varies with the size of the animal; therefore, in order to ascertain the amount of work that is really done by the liver in any case, it is necessary to know the quantity of bile secreted per kilogramme of body-weight in a unit of time. In all these experiments, therefore, the animals were weighed, so that the secretion of bile per kilogramme of body-weight might be determined.

Experiment 1.		Experiment 2.		Experiment 3.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	cc.	cc.	cc.	cc.	cc.
1·0		1·5		1·1	
0·85		1·47		0·85	
0·7		1·5		0·55	
0·75	0·394	1·4	0·307	0·6	0·17
0·75		1·5		0·75	
0·75		1·35		0·6	
0·75		1·5		0·6	
0·65	0·309	1·4	0·3	0·45	0·19
0·6		1·42		1·0	
0·45		1·4		0·75	
0·65		1·4		0·65	
0·55	0·381	1·5	0·312	0·7	0·177
0·75		1·47		0·45	
0·75		1·45		0·65	
0·85		1·42		0·8	
0·8	0·393	1·4	0·305	0·4	0·12
0·77		1·52		0·45	
0·77		1·37		0·45	
0·75		1·42		0·5	
0·8	0·355	1·42	0·301	0·45	0·133
0·7		1·37		0·55	
0·65		1·45		0·5	
0·55		1·4		0·5	
0·65	0·328	1·3	0·288	0·62	0·168
0·6		1·27		0·55	
0·65		1·32		0·6	
0·6		1·5		0·75	
0·7	0·292	1·3	0·267	0·65	0·123
0·5		1·25		0·4	
0·55		1·3		0·15	
0·47		1·15		0·65	
0·6		1·05			
	Mean. 0·351 cc.	1·2	*Mean.* 0·254 cc.		*Mean.* 0·154 cc.

In the three curara experiments detailed above, the mean secretion per kilogramme weight of the animal was 0·351 cc. in Experiment 1, 0·254, cc. in Experiment 2, and 0·154 cc. in Experiment 3. In the first case, the secretion was, from some unknown cause, unusually high: the last two coefficients will be found a much nearer indication of what is usual in the fasting animal, and in subsequent experiments it will be seen that the secretion is frequently below even the small coefficient in Experiment 3.

Undoubtedly the true test of hepatic work is the amount of bile *solids* secreted per unit of body-weight in a unit of time. Any one may calculate this from the analyses; but inasmuch as these were not made in every case, and seeing that we have found that whenever a substance increases the biliary secretion, it augments the excretion of bile-solids by the liver, even although the bile be rendered more watery, we have thought that a statement of the amount of *fluid bile* secreted per kilogramme of body-weight will be sufficiently refined for the purpcse of this research. Because the question we set ourselves to answer was principally this, What substances have the power of exciting the secreting apparatus of the liver?—a question which cannot be answered by the ordinary observations on man, for in his case it is impossible to determine whether an increased amount of biliary matter in the dejections be due—(1) To contraction of the gall bladder and larger bile ducts; (2) To the relief of some possible spasm of the larger bile ducts; or (3) To an increased secretion by the liver.

A second question before us was the relative powers as hepatic stimulants of the various substances employed. Our answer to this can only be approximative, for it would require a considerable number of experiments with any one substance to ascertain the most effective dose in the dog. This would entail an amount of suffering and of labour that seems altogether unwarranted by the result to be attained. We therefore believe that we do enough if we give a definite answer to the first of our questions, and an approximative answer to the second. The latter will be fairly well given by determining the amount of bile secreted per kilogramme of body-weight per hour.

ACTION OF CROTON OIL.

Röhrig has placed croton oil at the head of his list of hepatic stimulants, with the statement that in doses from eighteen drops to a "teaspoonful" it has an exciting effect on the biliary secretion even under the most unfavourable circumstances (*Op.* vi. p. 250). This substance was therefore made the subject of our earliest experiments.

Experiment 4. Dog weighing 7·3 kilogrammes.—Considering the small size of this dog, the secretion of bile was unusually great. This probably resulted from digestion being incomplete; for, although the animal was fed seventeen hours before the experiment, at death a quantity of elastic tissue, and a greyish fluid resembling chyme, were found in the stomach.

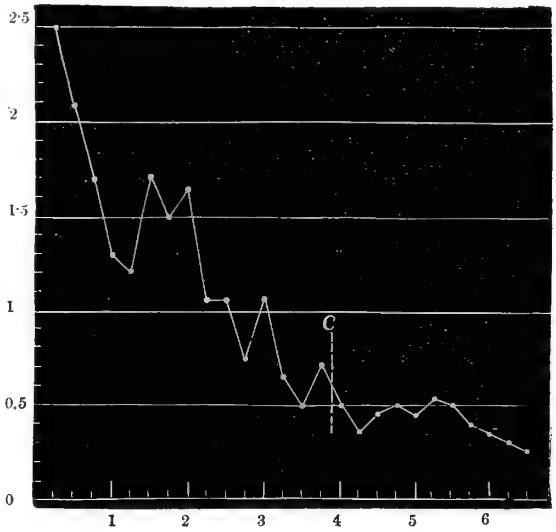

Fig. 4.—Secretion of bile when digestion was incomplete. 15 grains croton oil injected into duodenum at *c*.

After the secretion had fallen very low, 15 grains (about 30 drops) of croton oil, in 60 minims of almond oil, were injected directly into the duodenum (at *c*, fig. 4). The dose was a large one, but not so large as quantities given by Röhrig. After half-an-hour, the fall in the bile-secretion was arrested, and a slight rise took place. Towards the close of the experiment, the pulse became extremely weak.

Necropsy.*—The mucous membrane of the upper three-fourths of the small intestine was intensely red, especially in the duodenum, the colour of which resembled that of claret. There was evidence of impending purgation in the small intestine. The weak pulse at the close of this experiment, together with the violent intestinal irritation, suggested that the collapse had been occasioned by the drug, and that a smaller dose should be given in the next experiment.

Experiment 5. Dog weighing 5·9 kilogrammes.—This animal had refused almost all food for nearly two days. Six grains of croton oil in 60 minims of almond oil, were injected into the duodenum (*c*, fig. 5). No increase of the biliary secretion followed. The pulse became so weak that the experiment was ended two hours and a half after the oil was given.

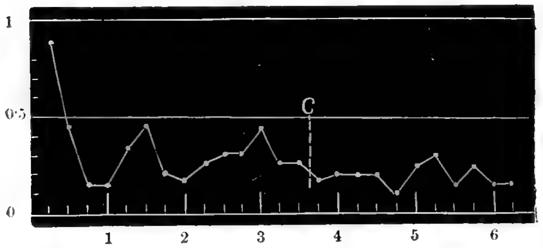

Fig. 5.—Secretion of bile before and after 6 grains of croton oil were injected into duodenum at *c*.

Necropsy.—The oil had found its way into the stomach. The gastric mucous membrane was of a claret colour. There was slight redness of the duodenum, but no evidence of purgative action.

Experiment 6. Dog that had fasted eighteen hours. Weight 3·1 kilogrammes.—In this experiment only 3 grains croton oil in 60 minims almond oil were injected into the duodenum. A decided increase in the biliary secretion began within an hour after the injection. The secretion soon reached a maximum, and then fell in the course of two hours to the same level as before the injection (fig. 6).

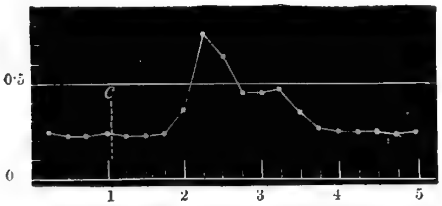

Fig. 6.—The secretion of bile before and after 3 grains of croton oil were injected into the duodenum at *c*.

Necropsy.—A portion of the oil was found in the stomach, and another portion half way down the small intestine. The gastric mucous membrane was intensely red. There were patches of slight redness here and there in the duodenum. No evidence of purgative action.

These experiments were undertaken simply to test the accuracy of Röhrig's conclusion arrived at by his method of counting the drops of bile. Our method,

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* In all cases, unless otherwise stated, the necropsy was performed immediately at the close of the experiment.

which, as we have explained, is far more reliable, gives no evidence that croton oil is to be regarded as more than a feeble hepatic stimulant; and, seeing that it has no reputation as such in practical medicine, we deemed further experimentation with it uncalled for. But as these experiments convinced us that RÖHRIG had, owing to the faultiness of his method, fallen into serious error, we deemed it necessary to subject all the substances he had employed, to our method of experimentation.

That there was no purgation from these doses of croton oil is a singular fact, which has been laid hold of by some persons as evidence that medicines affect the dog and man very differently, and that therefore the results seen in the one cannot be applied to the other. It is well known, however, that a difference in action is *quite exceptional*, and certainly the following experiments fully bear out this opinion. The only explanation of the non-purgative action of the oil in the above cases that suggests itself is, that possibly too great a dose of this violent irritant was introduced into the intestine, and that a paralysis of Lieberkühn's follicles was the result. The large doses were given in imitation of RÖHRIG's experiments.

ACTION OF RESINA PODOPHYLLI OR "PODOPHYLLIN."

Resina podophylli, or "podophyllin" as it is commonly termed, is very often employed in practical medicine for increasing the discharge of bile, but the physician is unable to say whether or not it really does stimulate the liver, for the result he observes might be due to an action of the agent on the bile-expelling mechanism. The maximum dose of podophyllin for a man is two grains.

Experiment 7. Dog that had fasted nineteen hours. Weight 15·3 kilogrammes. —The secretion of bile fell very gradually (fig. 7). Ten cubic centimetres of water were injected into the duodenum at *w*. There being no apparent effect, 100 cc. were injected at *w′*. The slight rise in secretion that ensued at the end of an hour may have been owing to this; but it is not likely, seeing that water is absorbed with rapidity. At *p*, ten grains podophyllin, suspended in 10 cc. water, were injected into the duodenum; and it is probable that the rise in secretion two hours afterwards was due to the podophyllin.

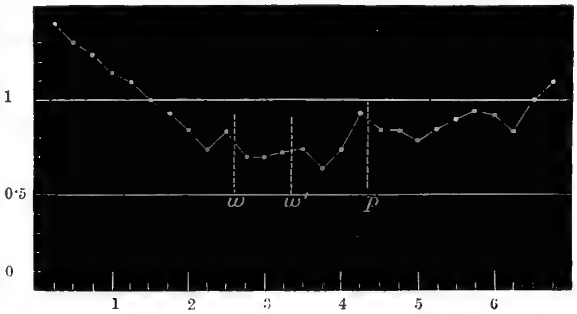

Fig. 7.—Secretion of bile before and after water and podophyllin. *w*, 10 cc. water; *w′*, 100 cc. water; *p*, 10 grains resina podophylli in 10 cc. water injected into duodenum.

Necropsy.—The mucous membrane of the duodenum, and to a slight extent below it, was very vascular, and this part of the intestine contained a considerable quantity of a slightly brown fluid, thereby affording evidence of a purgative effect.

Experiment 8. Dog that had fasted eighteen hours. Weight 6·6 kilogrammes.—Six grains podophyllin in 9 cc. water injected into duodenum (*p*, fig. 8). The subsequent rise in the bile-secretion is very evident. The secretion attained its maximum between three and four hours after the administration of the podophyllin. As in the previous case, the effect on the liver had very greatly diminished by the end of the sixth hour after administration.

Necropsy.—Distinct, though not abundant, evidence of purgative action in small intestine, and decidedly increased vascularity of the mucous membrane in its upper two-thirds. Nothing remarkable in stomach or large intestine.

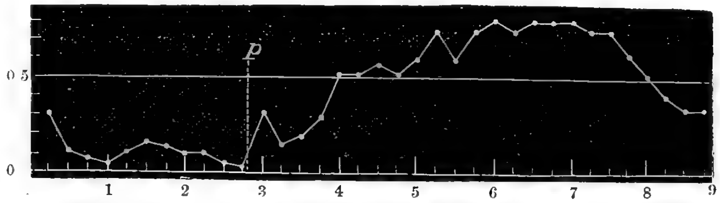

Fig. 8.—Secretion of bile before and after 6 grains of resina podophylli in 9 cc. water were injected into duodenum at *p*.

Experiment 8.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·3	0·042 cc.	0·57	0·477 cc.
0·1		0·52	
0·07		0·6	
0·05		0·75	
0·1		0·6	
0·15		0·75	
0·12		0·8	
0·1		0·75	
0·1		0·8	
0·05		0·8	
0·03		0·8	
p——		0·75	
0·32		0·75	
0·15		0·62	
0·2		0·52	
0·27		0·42	
0·52		0·35	
0·52		0·35	

Probably every one will be struck by the slowness and the small extent of the purgative action in these experiments, notwithstanding the large doses of podophyllin. That this was owing to the insolubility of podophyllin in water is probable from the two following experiments. Zwicke, Hagentorn, and Köhler having shown (Fraser's Report in *Op.* vii., vol. v. p. 393) that convolvulin, elaterin, and some other substances have no purgative action unless they come in contact with bile—which, therefore, appears to be a solvent for them—it occurred to us that the tardy action of the podophyllin might be owing to the non-entrance of the bile into the intestine. Accordingly in the next experiment, the podophyllin was suspended in bile.

Experiment 9. Dog that had fasted eighteen hours. Weight 11 kilogrammes.—12·2 cc. bile injected into duodenum (*b*, fig. 9). Unfortunately, there is a hiatus in the curve immediately before the injection, owing to a loss of the bile; nevertheless it is evident that increased bile-secretion followed the injection when the biliary flow had become fairly constant. Nine grains podophyllin, triturated in a mortar with 12 cc. bile, were injected into the duodenum (*p*). A rapid increase in the bile-secretion ensued; but it soon diminished, and three hours after the injection it was lower than it had ever been. In this remarkable experiment, therefore, the *diminution* of bile-secretion after podophyllin was far more remarkable than its increase; indeed, the increase might

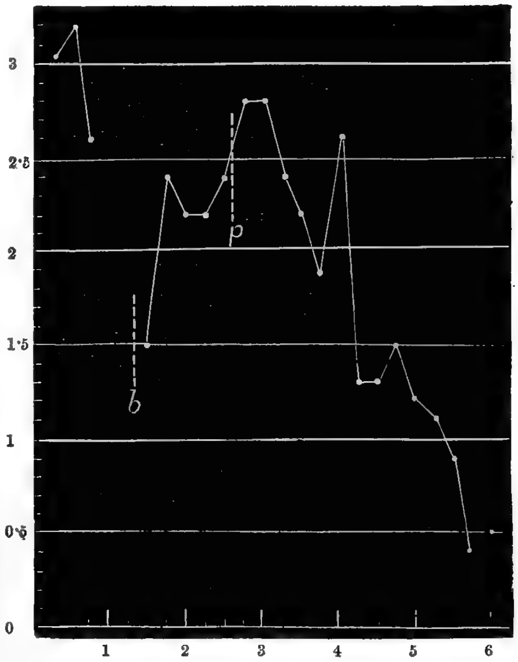

Fig. 9.—Secretion of bile before and after podophyllin. *b*, 12·2 cc. bile; *p*, 9 grains resina podophylli in 12 cc. bile injected into duodenum.

Experiment 9.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.	
3·05	
3·2	
2·6	
lost.	
lost.	
b ——	
1·5	
2·4	0·836 cc.
2·2	
2·2	
2·4	
p ——	
2·8	0·927 cc.
2·8	
2·4	
2·2	
1·9	0·645 cc.
2·6	
1·3	
1·3	
1·5	0·427 cc.
1·2	
1·1	
0·9	
0·4	
0·5	

possibly have been owing to the injected bile, and not to the podophyllin. Towards the close of the experiment the pulse became weak, but not excessively so.

NECROPSY.—Mucous membrane of stomach and whole length of small intestine *intensely red.* The small intestine contained a large quantity of fluid. The large intestine contained a considerable quantity of liquid fæcal matters. There was, therefore, abundant evidence that excessive purgation was imminent.

In this experiment, the intestinal irritation and the purgative effect were far greater than they were in any of the previous experiments with podophyllin, and it is evident that the principal change in the bile-secretion was *diminution.* It therefore appeared that, with a powerful solvent such as the bile, nine grains of podophyllin produced a too violent effect upon the alimentary canal. The previous experiments having shown that, with a slighter action on the intestine, there was a more powerful action on the liver, suggested that with a smaller dose of podophyllin given in the biliary solvent, an action on the liver would be evident, and that this would follow the injection more speedily than it had done in the experiments where the podophyllin was not given in a state of solution. The next experiment realised this anticipation in a very striking manner.

Experiment 10. Dog that had fasted nineteen hours. Weight 17·1 kilogrammes.—The bile-secretion was about 2 cc. per fifteen minutes before injection into the duodenum of 6 cc. bile and 6 cc. of water (*b*, fig. 10). The subsequent increase of secretion was trivial. An hour after this, four grains podophyllin, in the same quantity of bile and water, were injected (*p*). About half an hour afterwards a great acceleration of the biliary flow began, and lasted about an hour. In one of the periods of fifteen minutes, no less than 5·8 cc. of bile were secreted; a quantity never noticed in any other experiment, even on larger dogs. When this great hepatic excitement had disappeared, 6 cc. of bile and 6 cc. of water were again injected (*b′*), as in the first instance. The fall in the secretion was for a time arrested; but within three hours after the administration of the podophyllin, the action of the liver had almost entirely ceased. The pulse was weak, but not extremely so.

NECROPSY. — The mucous membrane of the duodenum was intensely vascular, but that of the remainder of the small intestine did not show an increased vascularity nearly so great as in the previous experiment. The upper three-fourths of the small intestine contained very decided evidence of purgative effect. The gastric mucous membrane had a dull red appearance.

Composition of Bile before and after Podophyllin.

The next question to be answered was evidently this, Is the increase in the quantity of bile after podophyllin merely due to an increase of water, or are the bile-solids also increased? The bile secreted by dog 10, between the second hour and a half and the third hour, and that secreted an hour and a quarter after the administration of podophyllin, were analysed with the following results (Table II).

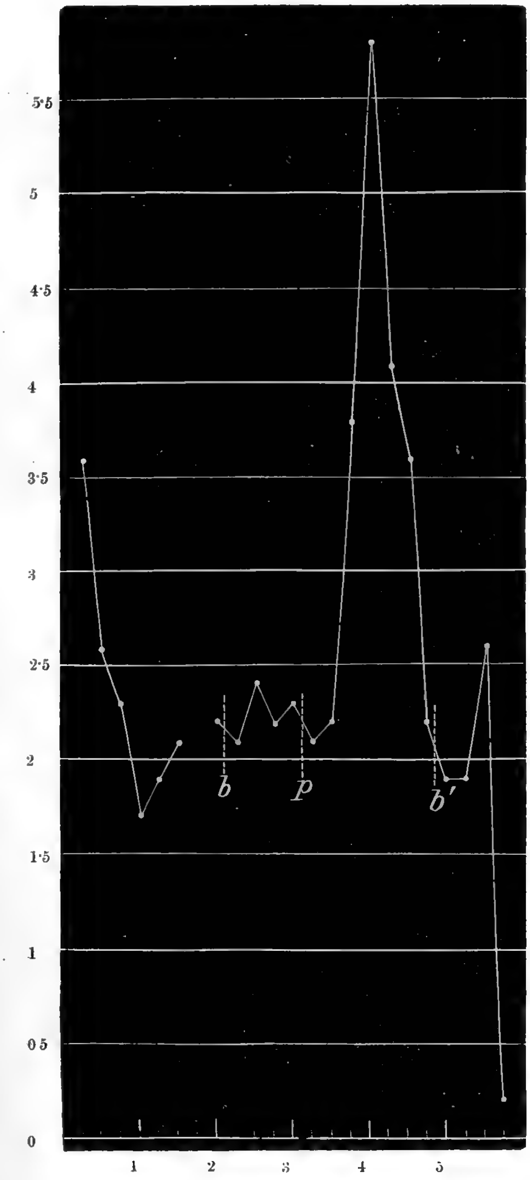

Fig. 10.—Secretion of bile before and after podophyllin. 6 cc. bile and 6 cc. water injected into duodenum at *b* and *b*′. 4 grains resina podophylli in the same fluids injected at *p*.

	Experiment 10.	
	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
	cc.	
	3·6	
	2·6	
	2·3	
	1·7	
	1·9	
	2·1	
	lost.	
	2·2	
b		
	2·1	0·526 cc.
	2·4	
	2·2	
	2·3	
p		
	2·1	
	2·2	
	3·8	1·01 cc.
	5·8	
	4·1	
	3·6	
	2·2	
b		
	1·9	
	1·9	
	2·6	
	0·2	

TABLE II.—*Podophyllin.*

Experiment 10.	Before.	After.
Water,	90·83	91·07
Bile acids, pigments, cholesterin, fats,	7·75	7·84
Mucus,	1·00	0·60
Ash,	0·42	0·49
	100·00	100·00
Velocity of secretion per half hour,	4·6 cc.	9·6 cc.

It thus appears that, notwithstanding the great velocity of bile-formation, the special bile-solids were not diminished; the only noteworthy diminution being in the amount of mucus. This remarkable result was confirmed by the following analysis of the bile in another case (Table III.).

TABLE III.—*Podophyllin.*

Experiment 10A.	Before.	After.
Water,	94·26	94·28
Bile-acids, pigments, cholesterin, fats,	4·66	4·68
Mucus,	0·73	0·70
Ash,	0·35	0·34
	100·00	100·00
Velocity of secretion per half-hour,	1·86 cc.	2·47 cc.

Results of the Experiments with Podophyllin.—1. Podophyllin, when injected into the duodenum of a fasting dog, increases the *secretion* of bile. It is inferred that the increased biliary flow in the preceding experiments was due to increased *secretion,* and not merely to *expulsion,* because the gall-bladder had been emptied by compression, and the cystic duct had been clamped: moreover, the increased flow was far too prolonged in some of the experiments to be attributable to spasm of the larger bile ducts; therefore, an increase in secretion must have been the cause. 2. When the bile is prevented from entering the intestine, the podophyllin acts less powerfully and less quickly than when bile is introduced. 3. Augmentation of the biliary secretion is most marked when the purgative effect is not severe; indeed, if the purgative effect be very decided (Experiment 9), diminution and not augmentation of the biliary secretion may be the chief result. 4. Podophyllin purgation is apparently due to a local action, for the irritation of the intestinal mucous membrane extends gradually from above downwards. It is a severe intestinal irritant. 5. The bile secreted under the influence of podophyllin, although it may be increased in quantity, contains as much of the special biliary matter as bile secreted under normal conditions.

These results are in exact accordance with clinical experience of the action of podophyllin in man, but in addition they show that this substance actually increases the *secretion* of biliary matter, and that the liver is stimulated to secrete bile of the normal composition. They therefore supply information of a precise and important character, which the observations on the human subject have failed to give.

In the experiments with podophyllin, performed by HUGHES BENNETT'S committee above referred to, it was found that podophyllin *diminishes* the secretion of bile. How is that statement to be reconciled with the above? The principal explanation is probably this, that in the experiments of the committee the doses given were large, and generally produced *profuse purgation.* We see that in Experiment 9 of this series diminished bile-secretion was the chief result of a dose that was too large, and it may be repeatedly observed in the following experiments:—1. That when a substance produces purgation, but does not stimulate the liver, it diminishes the secretion of bile. 2. That when a substance stimulates the liver as well as the intestinal glands, a moderate dose increases both the hepatic and the intestinal secretion, the effect on the former being most marked in the earlier part of the experiment, and diminishing as the purgative effect increases; but an excessive dose, by producing a violent purgative effect early in the experiment, may occasion nothing but diminished secretion of bile.

Speaking broadly—if in a fasting dog the administration of any substance cause the bile-secretion per hour, for every kilogramme of body-weight, to rise to 0·4 cc., the substance is to be regarded as a powerful hepatic stimulant. It will therefore be found of importance to compare the coefficients of secretion obtained after the administration of different substances. Necessarily, the results are only approximative, but are nevertheless of much value as furnishing for the first time the exact data necessary for a comparative estimate. Table IV. shows that in Experiment 10, the coefficient of secretion rose to the very high figure of 1·01 cc. per kilogramme per hour. It is to be admitted that the dose was excessive;[*] nevertheless it is worthy of remark, that we have found no other hepatic stimulant have so powerful an effect.

TABLE IV.

Podophyllin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per Hour.	
			Before.	After.
Experiment 8, .	6 without bile . .	0·90	0·04 cc.	0·47 cc.
„ 10, .	4 with bile . .	0·23	0·52 cc.	1·01 cc.

ACTION OF ALOES.

Aloes is very commonly employed as a purgative agent, but the physician has been unable to determine whether or not it affects the liver. The indefinite state of our information regarding it is shown by the following sentence—" By some observers the bile is asserted to be increased in quantity " after its administration (GARROD, *Op.* viii. p. 380). RÖHRIG (*Op.* vi.) found that in a rabbit aloes increases the secretion of bile, but his experiment is not satisfactory, for he found that the secretion stopped at the end of three hours.

Experiment 11. Dog that had fasted eighteen hours. Weight 8·6 kilogrammes.—Sixty grains of aqueous extract of Socotrine aloes in 12 cc. of water were injected into the duodenum (*a*, fig. 11). A decided increase in the biliary secretion was perceptible within half-an-hour thereafter. After attaining a maximum about an hour and a half after the administration of the drug, secretion gradually fell; but although the experiment was continued for seven hours after the aloes was given, the effect had not disappeared.

NECROPSY.—The aloes had extended along two-thirds of the small intestine, which contained about an ounce and a half of viscous fluid as the only evidence

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[*] This dose was doubtless much larger than need have been given, but when these earlier experiments were performed, we were under the impression that the dog requires larger doses than man. Further experience convinced us that this is exceptional. In many subsequent experiments we found that doses of various substances similar to those given to man act on the hepatic and intestinal glands of the dog.

of purgation. There was a decided increase in the vascularity of the mucous membrane in this part of the intestine. The stomach contained a little mucus. Its mucous membrane was pale.

Experiment 11.		Experiment 12.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·85	0·348 cc.	0·65	
0·9		0·42	
0·7		0·37	0·264 cc.
0·55		0·3	
a ——		0·35	
0·75		0·3	
1·05		*a* ——	
1·4		0·35	
1·15	0·697 cc.	0·97	
1·75		0·87	
1·55		0·85	
1·55		1·1	
1·4		1·2	0·93 cc.
1·3		1·05	
1·45		1·05	
1·45		1·35	
1·25		0·8	
1·25		1·15	
1·4		1·1	
1·25		1·15	
1·25		1·05	
1·2		1·05	
1·05		1·15	
1·15		0·9	
1·1			
1·2			
1·0			
0·65			
0·9			
0·9			
0·85			
0·8			

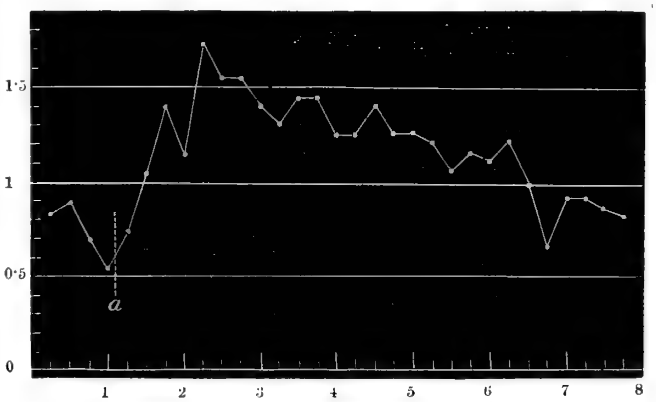

Fig. 11.—Secretion of bile before and after 60 grains extract of Socotrine aloes in 12 cc. of water were injected into the duodenum at *a*.

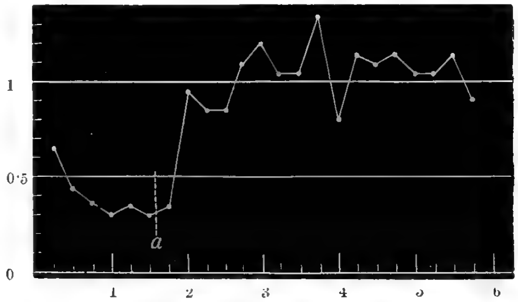

Fig. 12.—Secretion of bile before and after 60 grains extract of Socotrine aloes in 12 cc. water were injected into the duodenum at *a*.

Experiment 12. Dog that had fasted eighteen hours. Weight 5 kilogrammes.—Sixty grains* of extract of Socotrine aloes in 12 cc. of water were injected into the duodenum (at *a*, fig. 12). As in the previous experiment, the biliary secretion was increased within half an hour, and it became very strongly marked.

NECROPSY.—The aloes had extended half way down the small intestine. This portion of the intestine contained about two ounces of viscous fluid; and its mucous membrane, together with that of the stomach, was intensely red.

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* See preceding Note.

TABLE V.

Aloes.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per Hour.	
			Before.	After.
Experiment 11, .	60 without bile, .	6·9	0·34 cc.	0·69 cc.
„ 12, .	60 „ „ .	12·0	0·26 cc.	0·93 cc.

Composition of the Bile before and after Aloes.

It is evident from Tables VI. and VII. that, under the influences of aloes, the bile became more watery; nevertheless, the amount of bile-solids secreted per unit of time increased.

TABLE VI.—*Aloes.*

Experiment 11.	Before.	After.
Water, ...	84·11	91·44
Bile-acids, pigments, cholesterin, fats, ...	12·45	7·53
Mucus, ...	1·77	0·38
Ash, ...	1·67	0·65
	100·00	100·00
Velocity of secretion per half-hour, ...	1·5 cc.	2·65

TABLE VII.—*Aloes.*

Experiment 12.	Before.	After.
Water, ...	83·93	86·75
Bile-acids, pigments, cholesterin, fats, ...	12·30	10·79
Mucus, ...	2·74	1·49
Ash, ...	1·03	0·97
	100·00	100·00
Velocity of secretion per half-hour, ...	0·66 cc.	2·2 cc.

Results of Experiments with Aloes.—1. Sixty grains of the extract of Socotrine aloes, when placed in the duodenum, without bile, powerfully stimulated the liver, causing the coefficient of secretion to rise in Experiment 11 to 0·69 cc., and in Experiment 12 to 0·93 cc. The doses given were, however, so excessive —the maximum dose for a man being 6 grains—that it would be misleading to infer that the small doses given to man produce a decided effect on his liver. Yet we have definitely proved that this substance really does increase the secretion of bile. 2. Under its influence the liver excreted a greater quantity of biliary matter in a given time, although the bile was rendered more watery. 3. Coincident with the marked action on the liver there was only slight purgation.

ACTION OF RHUBARB.

As rhubarb gives to the dejections an appearance similar to that due to an increased discharge of bile, it is not possible from observations on the human subject to arrive at a definite conclusion regarding its influence on the liver. In consequence of this, in the latest works on Materia Medica, its action on the liver is ignored. The following experiments, however, prove that it stimulates the liver. The ordinary infusion of the "British Pharmacopœia" was made with Indian rhubarb; it was then filtered and concentrated until 5 cc. contained the active part of seventeen grains of rhubarb. This was the dose employed. Thirty grains is the maximum dose for a man.

Experiment 13. Dog that had fasted fifteen hours. Weight 22·2 kilogrammes. —5 cc. of the above infusion of rhubarb were injected into the duodenum four times in succession (r, r', r'', r''', fig. 13). Within half-an-hour after every dose there was an increase in the biliary secretion.

Experiment 13.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·15	0·173 cc.	r''	
0·95		1·55	0·279 cc.
0·95		1·8	
0·80		1·45	
r		1·4	
0·95		r'''	
1·3		2·0	0·322 cc.
1·15		1·85	
r'		1·9	
1·5	0·27 cc.	1·4	
1·65		1·45	
1·45		1·15	
1·4		1·4	

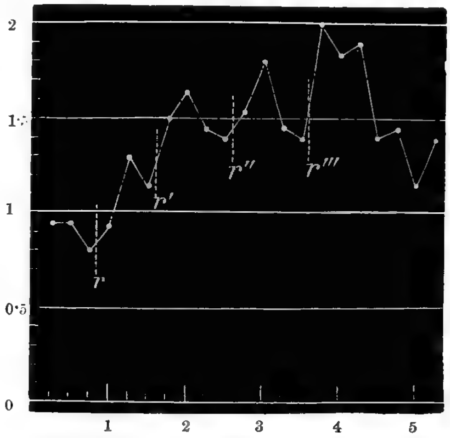

Fig. 13.—Secretion of bile before and after 5 cc. of a concentrated infusion of rhubarb were injected into duodenum at r, r', r'', r'''.

Necropsy.—The rhubarb had extended along about a third of the small intestine. There was no unusual redness of the mucous membrane, and there was only slight evidence of purgative action.

Experiment 14. Dog that had fasted eighteen hours. Weight 13·4 kilogrammes. —The artificial respiration, which was deficient at the commencement of this experiment, was improved at *a*, fig. 14. This was followed by an increase in the secretion, of short duration: 5 cc. of the same infusion of rhubarb as that used in the previous experiment were injected into the duodenum three times in succession (*r*, *r′*, *r″*, fig. 14). The biliary secretion was augmented within half-an-hour after each injection.

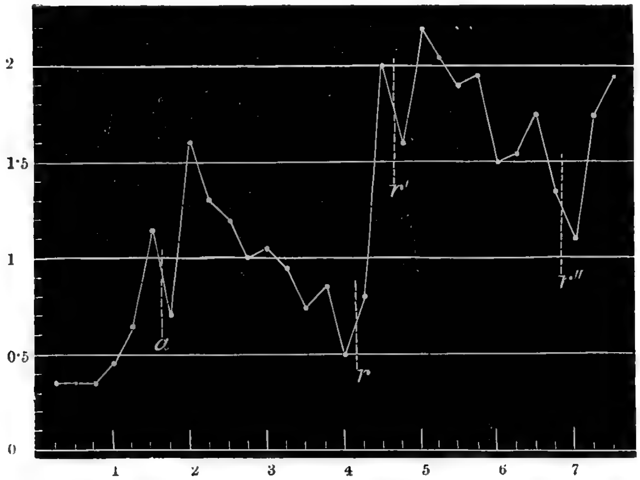

Fig. 14.—Secretion of bile before and after rhubarb. Artificial respiration improved at *a*. 5 cc. concentrated infusion of rhubarb injected into duodenum at *r*, *r′*, and *r″*.

Experiment 14.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·37		*r* ——	
0·37		0·8	
0·35		2·0	
0·45		*r′* ——	
0·65		1·6	
1·15		2·2	0·604 cc.
0·7		2·05	
1·6		1·9	
1·3		1·95	
1·2		1·5	
1·0		1·55	
1·05		1·72	
0·95	0·227 cc.	1·37	
0·75		*r″* ——	
0·85		1·1	
0·5		1·75	
		1·97	

Necropsy.—The rhubarb had extended along four-fifths of the small intestine. There was no unusual redness of the mucous membrane. The portion of intestine through which the rhubarb had extended contained 120 cc. of a thick yellowish fluid: there was, therefore, decided evidence of purgative action.

The amount of water given with the rhubarb in these experiments was so trivial that it may be entirely disregarded.

TABLE VIII.

Rhubarb.	Total Dose in Grains.	Grains per kilogramme of Body-weight.	Secretion of Bile per kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 13, .	68 without bile,	3·06	0·17 cc.	0·32 cc.
" 14, .	51 " "	3·8	0·22 cc.	0·60 cc.

Composition of the Bile before and after Rhubarb.

TABLE IX.—*Rhubarb.*

Experiment 13.	Before.	After the Second Dose.	At the Close of the Experiment.
Water, ...	88·80	89·28	88·98
Bile-acids, pigments, cholesterin, fats, ...	9·60	9·60	9·60
Mucus, ...	1·00	0·60	0·80
Ash, ...	0·60	0·52	0·62
	100·00	100·00	100·00
Velocity of secretion per half-hour	1·9 cc.	2·95 cc.	2·55 cc.

TABLE X.—*Rhubarb.*

Experiment 14.	Before.	After.
Water, ...	85·47	86·23
Bile-acids, pigments, cholesterin, fats, . . .	11·59	11·03
Mucus, ...	1·87	1·72
Ash, ...	1·07	1·02
	100·00	100·00
Velocity of secretion per half-hour, ...	1·45 cc.	3·95 cc.

It therefore appears that rhubarb, like podophyllin, excites the liver to secrete bile, having a composition similar to that secreted under normal conditions.

Results of Experiments with Rhubarb.—1. An infusion of seventeen grains of Indian rhubarb, when placed in the duodenum, never failed to increase the secretion of bile within half-an-hour after it was given. Although in Experiment 14, the coefficient of secretion was raised to 0·6 cc., thereby indicating a very active secretion of bile, it must be observed that in this case the action of the liver was irregular. Experiment 13 is, therefore, a better index of the activity of the drug, and as in that case sixty-eight grains of the substance did not raise the secretion of bile higher than 0·32 cc., we may conclude that, although rhubarb is a hepatic stimulant, it is not a powerful one—a conclusion completely in harmony with the results of observations on man. 2. The bile, although secreted in increased quantity, had the composition of normal bile as regards the biliary constituents proper. 3. The doses which excited the liver had in one case no marked purgative effect, but in another case the purgative effect was considerable.

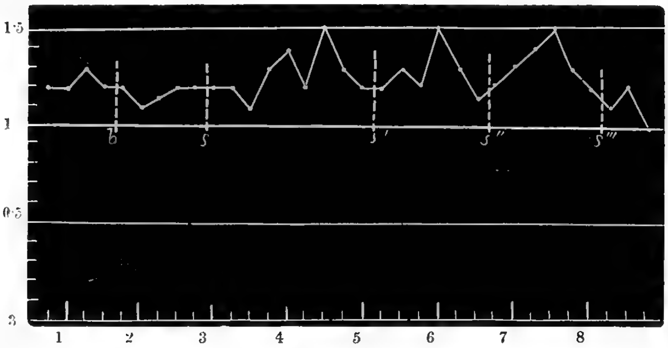

Fig 15.—Secretion of bile before and after senna. ½ cc. bile and 5 cc. water injected into duodenum at *b*. ½ cc. bile and 5 cc. concentrated infusion of senna injected into duodenum at *s*, *s′*, *s″*, and *s‴*.

Experiment 15.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·2	0·212 cc.	1·2	
1·2		*s′* ——	
1·3		1·2	
1·2		1·3	
b ——		1·2	
1·2		1·5	
1·1		1·3	
1·15		1·17	
1·2		*s″* ——	
1·2		1·2	0·238 cc.
s ——		1·3	
1·2		1·4	
1·2		1·5	
1·1		1·3	
1·3		1·2	
1·4		*s‴* ——	
1·2		1·1	
1·5		1·2	
1·3		1·0	

Action of Senna.

Senna is a well-known purgative agent. Probably no physician has ever ascribed to it any cholagogue property, and had not Röhrig stated (*Op.* vi.) that it excites the liver as much as rhubarb, we should not have deemed its powers worthy of investigation. The ordinary infusion of senna of the "British Pharmacopœia" was prepared and concentrated until 5 cc. contained the active part of forty-five grains of senna; a small dose for a man.

Experiment 15. Dog that had fasted eighteen hours. Weight 23·1 kilogrammes.—½ cc. bile and 5 cc. water were injected into duodenum at *b* (fig. 15), and ½ cc. bile, with 5 cc. infusion of senna of the strength above mentioned, at *s*, *s′*, *s″*, *s‴*. There was only a slight increase in the biliary secretion.

Necropsy. — The senna had passed through the whole length of the small and had entered the large intestine. The amount of fluid in the small intestine was 103 cc., showing that a very considerable purgative effect had been produced.

Result of Experiment with Senna. — Although senna is a powerful intestinal, it is a very feeble hepatic stimulant. Röhrig's error with regard to it was doubtless the result of his faulty method.

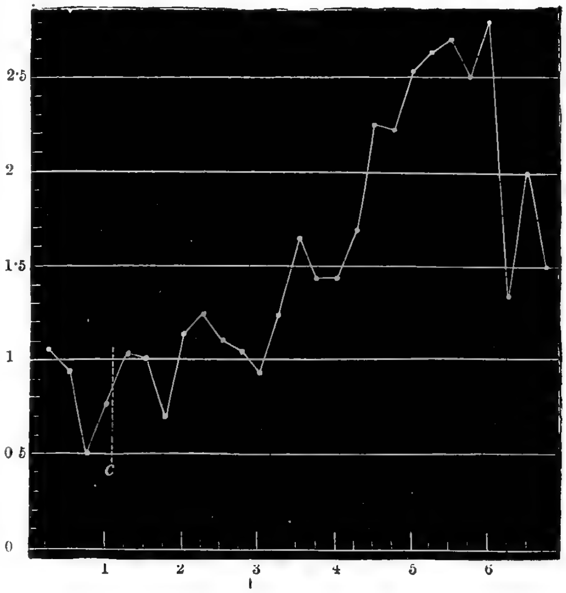

Fig. 16.—Secretion of bile before and after 60 grains extract of colchicum in 10 cc. water were injected into the duodenum at *c*.

Action of Colchicum.

Colchicum has been recommended by Garrod as a cholagogue in cases of gout, but its action on the liver has not hitherto been tested by direct experiment. Two grains of the extract is the maximum dose for a man.

Experiment 16.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·07	0·138 cc.	1·25	0·246 cc.
0·92		1·65	
0·5		1·45	
0·77		1·45	
c ——		1·7	0·371 cc.
1·02	0·207 cc.	2·25	
1·0		2·22	
0·7		2·55	
1·15		2·65	0·453 cc.
1·25	0·227 cc.	2·7	
1·1		2·5	
1·05		2·8	
0·95		1·36	
		2·0	
		1·5	

Experiment 16. Dog that had fasted sixteen hours. Weight 23·5 kilogrammes.—Sixty grains of the aqueous extract of colchicum of the "British Pharmacopœia" in 10 cc. of water were injected into the duodenum (*c*, fig. 16). In an hour the biliary secretion began to increase, and five hours after the injection it was nearly five times more than before the drug was given. The secretion then fell, and just at the close of the experiment a large quantity of liquid fæces was discharged. The rise in the curve in fig. 16 suggests a very powerful stimulation of the liver, but it must be remembered that the animal was of large size, and the table of numbers shows that the secretion per kilogramme of dog never went higher than 0·453 cc.

Necropsy.—There was great vascularity of the upper four-fifths of the mucous membrane of the small intestine. The vascularity of the duodenum was intense. The mucous membrane of the large intestine was also unusually vascular. The gastric mucous membrane was pale. There was evidence of considerable hydrocatharsis in the small intestine. The large intestine was empty, owing to the recent discharge of fæcal matter.

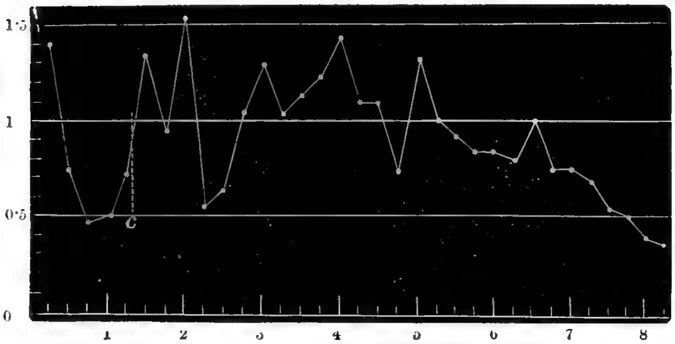

Fig. 17.—Secretion of bile before and after 60 grains of aqueous extract of colchicum in 10 cc. of water were injected into duodenum at *c*.

Experiment 17.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·42		1·1	
0·75	0·1 cc.	1·1	
0·47		0·75	
0·5		1·35	
0·72		1·0	
c ——		0·95	
1·35	0·186 cc.	0·85	
0·95		0·85	
1·55		0·8	
0·55		1·0	
0·62		0·75	
1·02		0·75	
1·3		0·7	
1·02	0·205 cc.	0·55	
1·15		0·5	
1·22		0·4	
1·47		0·37	

Experiment 17. Dog that had fasted eighteen hours. Weight 23·6 kilogrammes.—Sixty grains of aqueous extract of colchicum in 10 cc. of water were injected into the duodenum (*c*, fig. 17). Although the biliary flow thereafter varied much, a decided increase was evident an hour and a half after the administration of the drug. The increase lasted about four hours, after which the secretion gradually fell. The liver was certainly excited, but not powerfully, for the secretion of bile per kilogramme of dog did not rise above 0·205 cc.

Necropsy.—There was increased vascularity of the mucous membrane of the upper three-fourths of the small intestine. The whole small intestine contained evidence of powerful cathartic action.

TABLE XI.

Colchicum.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 16, .	60 without bile,	2·5	0·13 cc.	0·45 cc.
„ 17, .	60 „ „	2·5	0·1 cc.	0·2 cc.

TABLE XII.—*Composition of the Bile before and after Colchicum.*

Experiment 17.	Before.	After.
Water, ...	88·434	90·63
Organic Bile-solids, ...	10·616	8·75
Ash, ...	0·950	0·62
	100·00	100·00
Velocity of bile-secretion per half hour, ...	1·2 cc.	2·24 cc.

It appears from the above analysis that colchicum rendered the bile more watery; nevertheless, owing to the increased velocity of secretion, more biliary matter was excreted by the liver under its influence.

Results of Experiments with Colchicum.—1. Sixty grains of the aqueous extract of colchicum powerfully excited the liver in Experiment 16, but feebly in Experiment 17; yet, in both cases, the relation of the dose to the size of the animal was the same. In the latter case the purgative action was more marked, and the decided fall in the curve at the close of the experiment, as well as the never very great excitement of the liver, was probably due to the greater purgation. The dose was needlessly large; but we were still under the erroneous idea that the dog requires larger doses of drugs. 2. Although colchicum increases the amount of biliary matter secreted by the liver, it renders the bile more watery.

As in all the preceding experiments, the drugs stimulated the intestinal glands as well as the liver, and as the podophyllin experiment (9) and the colchicum experiment (17) seemed to show the stimulating effect of the molecules of a substance on the liver may be overcome by a very powerful action on the intestinal glands, it was obviously important to ascertain the effect which a *purely intestinal stimulant* has on the *bile-secreting* mechanism. The following experiments with magnesium sulphate, castor-oil, gamboge, and ammonium chloride afford conclusive evidence regarding this point of great importance in practical medicine; regarding which it ought to be observed that, although the physician has correctly pointed out that certain substances increase the discharge of bile, he has never detected the fact that purely intestinal purgatives diminish the biliary flow. Nor is this surprising, for, when the fæcal matters are much diluted by secretion from the intestinal glands, it is impossible from their appearance to say whether or not the normal quantity of bile has been discharged into the duodenum.

Action of Magnesium Sulphate.

Experiment 18. Dog that had fasted seventeen hours. Weight 5·4 kilogrammes (fig. 18).

Necropsy.—Great purgative action in upper half of small intestine. Mucous membrane intensely reddened.

Experiment 19. Dog that had fasted seventeen hours. Weight 8·2 kilogrammes (fig. 19).

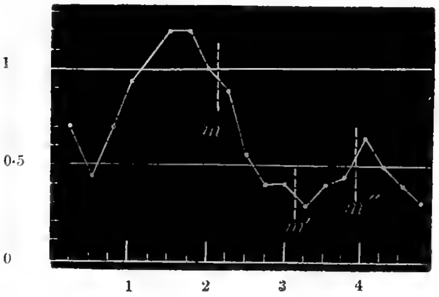

Fig. 18.—Secretion of bile before and after magnesium sulphate. 60 grains in 6 cc. water injected into duodenum at *m*, *m'*, and *m''* (180 grains given in all).

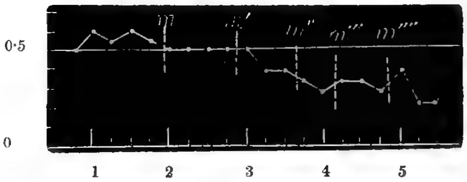

Fig. 19.—Secretion of bile before and after magnesium sulphate. 60 grains in 12 cc. water at *m*. 60 grains in 6 cc. water at *m'*, *m''*, *m'''*, and 120 grains in 12 cc. water at *m''''*, all injected into duodenum (360 grains given in all).

Necropsy.—Small intestine contained 90 cc. of fluid, whereas only 42 cc. had been injected. There was, therefore, evidence of decided purgation, and there was intense irritation of the mucous membrane in the upper half of the small intestine.

Result of Experiments with Magnesium Sulphate.—Experiments 18, and more especially 19, show that magnesium sulphate does not increase but, on the contrary, lessens the biliary secretion. The fall in secretion was probably due to an indirect effect of the action of the substance on the intestinal glands.

Action of Castor-Oil.

As Röhrig experimented with castor-oil (*Op.* vi.), and found that it has scarcely any effect on the hepatic secretion, it appeared desirable to emulsify the oil with bile, so that its condition in the intestine might more closely resemble that in any normal case.

Experiment 20. Dog that had fasted eighteen hours. Weight 7·7 kilogrammes.—3 cc. of bile were injected into the duodenum at *b* (fig. 20). One ounce of castor-oil, emulsified with 3 cc. of bile, was injected into the duodenum at *c*, and again at *c′*. A slight increase in the bile-secretion followed the second dose; but as its extent was trifling, it should probably be disregarded. There was a great diminution towards the close of the experiment.

Necropsy.—There was decided evidence of purgation in the small intestine. There was no unusual redness of the mucous membrane, save at the lower part of the duodenum.

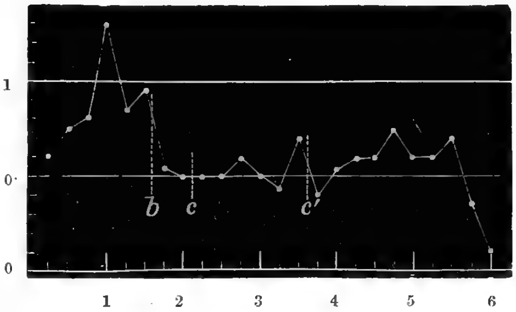

Fig. 20.—Secretion of bile before and after castor-oil. 3 cc. of bile injected into the duodenum at *b*. The same, with one ounce of castor-oil, given at *c*, and at *c′*.

Experiment 21. Dog that had fasted eighteen hours. Weight 24·5 kilogrammes.—3 cc. bile injected into the duodenum at *e* (fig. 21), and 28·5 cc. castor-oil with 3 cc. bile injected at *o*, and again at *o′*.

Necropsy.—The oil had extended throughout the whole length of the small and large intestine. There was evidence of profuse purgative action, but the increased vascularity of the intestinal mucous membrane was slight.

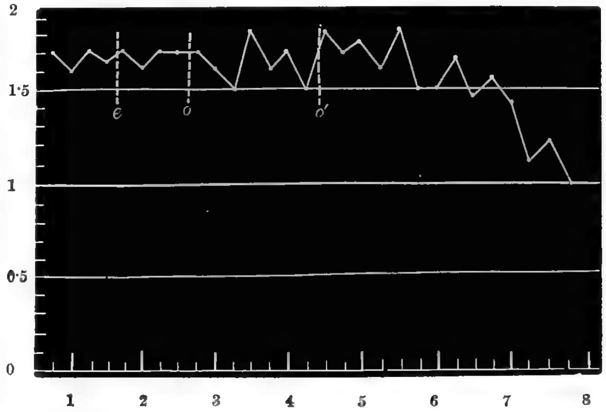

Fig. 21.—Secretion of bile before and after castor-oil. 3 cc. bile injected into duodenum at *e*. The same with 28·5 cc. castor-oil injected at *o*, and again at *o′*.

Result of Experiments with Castor-Oil.—It stimulates the intestinal glands, but not the liver. It lowers the bile-secretion, probably indirectly, owing to its action on the intestinal glands. The appearance of the intestinal mucous membrane was in complete harmony with the belief that castor-oil is an exceedingly bland purgative.

Action of Gamboge.

Experiment 22. Dog that had fasted eighteen hours. Weight 4·8 kilogrammes. —3 cc. of bile and 3 cc. of water were injected into the duodenum at *b* (fig. 22). Previously to this there was, considering the small size of the dog, a large secretion of bile. The increased secretion which followed the injection was probably owing to the action of the bile. Twenty grains of gamboge in the same quantity of bile and water were given at g, and 40 grains in the same fluid at g'. Half an hour after the first dose there was a decided acceleration of the biliary flow, but in an hour afterwards it had temporarily sunk nearly to zero. If the mean be taken, it will be found that the increase of secretion was so slight that it might have been due to the bile that was given with the gamboge. On the whole, therefore, it can scarcely be said that the amount of bile secreted was increased by the gamboge, and certainly the next experiment lent no support to such a view of the matter.

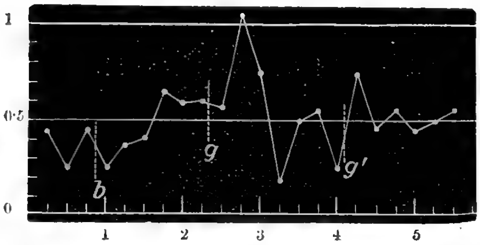

Fig. 22.—Secretion of bile before and after gamboge. 3 cc. bile and 3 cc. water injected into duodenum at *b*; 20 grains gamboge at g, and 40 grains at g', in the same fluid injected into duodenum.

Necropsy.—There was great redness of the mucous membrane in the upper half of the small intestine. There was evidence of profuse hydrocatharsis in this portion of the gut. Some of the gamboge had passed into the stomach, the mucous membrane of which was somewhat reddened.

Experiment 23. Dog that had fasted nineteen hours. Weight 8 kilogrammes. —1 cc. of bile and 2 cc. of water were injected into the duodenum at *b* (fig. 23); 4 grains of gamboge in 0·2 cc. of bile and 2 cc. of water were injected at g, g', and g''. At g''', g^{iv}, g^{v}, twice the amount of gamboge was given in the same fluid. The increase in the bile-secretion after the first dose was trifling. The chief result of the experiment was *diminution* of the secretion.

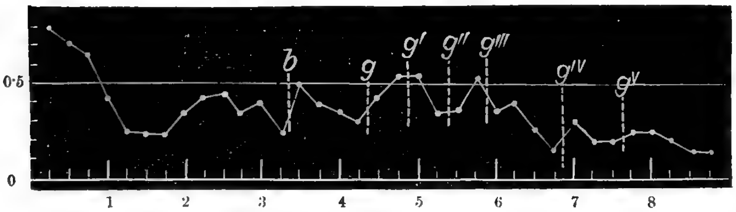

Fig. 23.—Secretion of bile before and after gamboge. (See text.)

Necropsy.—There was profuse hydrocatharsis in the small intestine. There was no very noteworthy increase in the vascularity of the mucous membrane.

In Experiment 23 a smaller quantity of bile was given than in Experiment 22, in order to eliminate, as far as possible, its stimulating effect on the liver: 23 is therefore a better experiment than 22.

Result of Experiments with Gamboge.—It is a powerful hydrocathartic, but is not a hepatic stimulant. It is extremely interesting to contrast the negative effect on the liver of this hydrocathartic with the positive effect of colchicum, also a hydrocathartic. In both there was violent irritation of the mucous membrane of the duodenum and small intestine generally. And it is important to observe that in the case of gamboge this irritation gave rise to no increased action of the liver, showing *that duodenal irritation is not of necessity followed by hepatic excitement.*

Action of Ammonium Chloride.

According to Garrod (*Op.* viii. p. 51), chloride of ammonium is "by some considered a cholagogue." The most valuable evidence which we have regarding the action of this substance is that furnished by Dr Stewart of Brecon (*Op.* ix. p. 316). The large experience in the treatment of hepatic affections acquired by Dr Stewart in India has led him to regard ammonium chloride as an invaluable agent in the treatment of active hepatic congestion, chronic hepatitis, and in "torpor of the liver," associated with congestion of the organ and lithæmia. Many such cases he has seen cured by from ten to twenty grain doses, given twice or thrice daily, with attention to diet, rest, and such other general indications. The drug produces diuresis, a sensation of warmth beginning in the epigastrium and gradually extending over the whole body, diaphoresis, exhilaration of the nervous system, and an undoubted effect on the liver, as shown, not only by gradual disappearance of the symptoms referable to hepatic congestion, but by other and more immediate signs, "peculiarly and directly referable to the liver and related parts." Thus, within five minutes or half an hour after a dose of the salt, the patient may experience one or more "shocks" as of "something giving way," or a "pricking" or "gnawing" sensation in the hepatic region. In addition to these, a full dose increases intestinal peristalsis, "as evidenced by the twisting and other movements experienced in the situation of the duodenum, or all over the abdomen, and which, at times, are more sensibly felt in the situation of the umbilicus, or in the inguinal region. The abdominal muscles may also be thrown into tonic contractions, which are perceptible at times to both sight and touch. "Torpor of the liver," and functional derangements attended by lithæmia (Murchison), associated with congestion of the liver, want of sleep, and depression of spirits, are benefited in a remarkable manner by a course of ammonium chloride, with careful attention to diet and regimen. In such cases, he has known a few twenty-grain doses of the salt "remove symptoms of disordered liver, restore sleep, and revive the drooping spirits, after the failure of other remedies." Dr Stewart, however, nowhere says that he ever observed any cholagogue effect of this remedy.

Experiment 24. Dog that had fasted eighteen hours. Weight 7 kilogrammes (fig. 24).

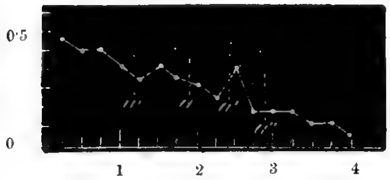

Fig. 24.—Secretion of bile before and after ammonium chloride. 6 cc. water injected into duodenum at *w*. The same with 6 grains ammonium chloride, injected at *a*, and again at *a′* and *a″* (18 grains given in all).

Necropsy.—Small intestine, in nearly its whole length, contained a large quantity of a very watery fluid. The vascularity of the mucous membrane was only slightly increased.

Experiment 25. Dog that had fasted twenty hours. Weight 13·7 kilogrammes (fig. 25).

Necropsy.—Somewhat increased vascularity of the mucous membrane of the upper three-fourths of the small intestine. There was evidence of a moderate purgative effect.

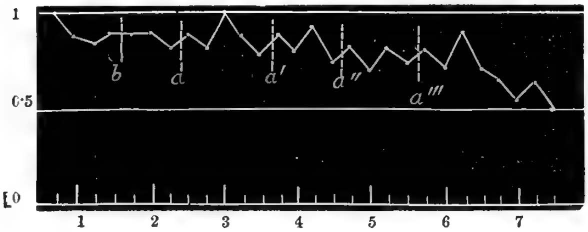

Fig. 25.—Secretion of bile before and after ammonium chloride. ½ cc. bile and 5 cc. water injected into duodenum at *b*. The same with 10 grains ammonium chloride injected at *a*. At *a′* the same with 20 grains, at *a″* the same with 40 grains, at *a‴* the same with 60 grains.

Experiment 25.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog; per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·00	0·267 cc.	0 95	
0·90		0·77	
0·87		*a″* ——	
0·90		0·80	
b ——		0·70	
0·90		0·80	
0·90		0·75	
0·85		*a‴* ——	
a ——		0·80	
0·90		0·70	
0·85		0·90	
1·00		0·70	
0·90		0·65	0·169 cc.
0·80		0·55	
a′ ——		0·62	
0·90		0·50	
0·80			

Result of Experiments with Ammonium Chloride.—The two experiments with this substance show that doses capable of stimulating the intestinal glands did not excite the liver. The effect on the biliary secretion is comparable to that of sulphate of magnesia (Experiments 18 and 19), or other substance having a stimulant effect on Lieberkühn's glands, but not on the liver. In proportion to the body-weight, the doses we gave to the dog were greater than those given to man, and therefore it need not be expected that, in the doses recommended by Dr Stewart, a purgative effect should be observed in man. Inasmuch, therefore, as these experiments give no evidence of any stimulant action of this substance on the liver, and seeing that in the human subject also there is no certain evidence of its having any *direct* cholagogue action, one is led to ask whether the effects observed by Dr Stewart, in cases of chronic hepatic torpidity, may not have been the result of some indirect action on the liver, due to a slight but prolonged increase of the intestinal secretion, or to some effect on the system generally. Our experiments supplement Dr

Stewart's observations, and plainly narrow the range of speculation in searching for a rational theory of the action of the drug in hepatic congestion.

These experiments (Nos. 18 to 25), with purely intestinal stimulants, all point to one great fact, that *intestinal purgation per se lowers the bile-producing function of the liver*, and it may therefore be inferred, that when the molecules of a substance have the double effect of exciting the liver as well as the intestinal glands, the former effect has in some measure to contend with the latter, and may indeed be overcome by it, if the purgative effect be rapid and severe. This has been already pointed out in Experiment 9, and indeed it may be generally observed, that although a substance with this twofold effect excites the liver in the early part of the experiment, the secretion of bile soon begins to diminish as the substance finds its way down the intestinal canal and implicates a greater and greater number of Lieberkühn's glands. (See Experiments 10, 17.) In the concluding observations an important indication for the guidance of the physician will be deduced from this significant fact.

Action of Scammony.

The resin of scammony, being insoluble in water, was dissolved in dilute alcohol, and some bile was added, in order still further to promote its absorption from the alimentary canal.

Experiment 26. Dog that had fasted eighteen hours. Weight 9·5 kilogrammes.—2·5 cc. bile were injected into the duodenum (*b*, fig. 26). This produced no notable effect. Twenty grains of scammony resin dissolved in 3·5 cc. rectified spirit, 3 cc. water and 3 cc. bile were then injected (*s*), and this dose was afterwards repeated (*s*′). There was a slight increase in the biliary secretion.

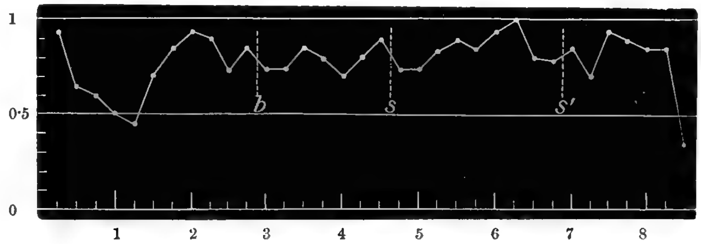

Fig. 26.—Secretion of bile before and after scammony. Bile injected into duodenum at *b*, and scammony with bile and alcohol at *s* and *s*′. (See text.)

Necropsy.—There was greatly increased vascularity of the mucous membrane of the whole length of the small intestine. Vascularity of the gastric mucous membrane was also somewhat increased. There was evidence of severe purgative action in the whole extent of both the small and large intestine.

Experiment 26a. Dog that had fasted nineteen hours. Weight 6·8 kilogrammes.—In this experiment it was determined to give scammony in smaller doses. 1 cc. bile and 2 cc. water were injected into the duodenum at *b*, fig. 26a.

The exact effect of this was not ascertained, owing to the loss of the bile secreted during one of the periods. About an hour after this, 0·25 cc. bile, 0·5 cc. rectified spirit, and 1·25 cc. water, were injected (*b*′). This having scarcely any effect, it was given with four grains of scammony resin at *s*, and again at *s*′. The amount of scammony was doubled, and this dose was given at *s*″ and *s*‴. There was an increase of the biliary secretion after the first two doses of scammony, but after the third and fourth the secretion diminished.

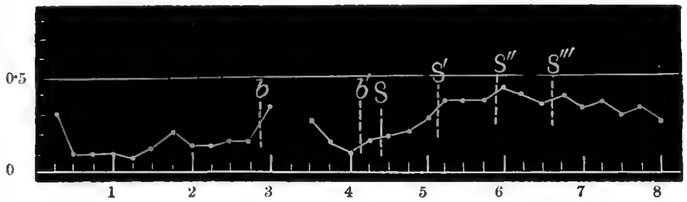

Fig. 26A.—Secretion of bile before and after scammony. Bile given at *b* and *b*′; scammony, &c., given at *s*, *s*′, *s*″, *s*‴. (See text.)

As two experiments (73, 74) in which alcohol was given, prove that it certainly does not augment the biliary secretion, this experiment shows that scammony is a hepatic stimulant, although not a powerful one.

NECROPSY.—The scammony had passed along two-thirds of the small intestine. There was decided evidence of purgation, but no remarkable increase in the vascularity of the mucous membrane.

From these experiments it appears that scammony is a hepatic stimulant of feeble power, and it seems unnecessary to detail them further.

ACTION OF RESINA EUONYMI OR "EUONYMIN."

It is stated by WOOD and BACHE (*Op.* x. p. 374), that "the precise virtues of the bark of *Euonymus atropurpureus* have not been determined." Mr C. A. SANTOS—quoted by them—describes it as "tonic, hydragogue cathartic, diuretic, and antiperiodic." Dr TIDYMAN informed them that he had obtained useful effects from it, as an alterative of the hepatic function. WOOD and BACHE conclude that "on the whole its character is somewhat uncertain; and it might well form a subject of further examination." The American "Eclectics"* give "euonymin" as a mild aperient in doses of from 1 to 2 grains. The substance used by them, however, is an impure resin, only a portion of which consists of the active principle—the *true* euonymin. Mr CLOTHIER (*Op.* x. *l. c.*) found it to produce active purgation without griping. The substance employed in our experiments is an impure resin, said to be prepared by precipitating the tincture of euonymin with water acidulated with hydrochloric acid, and mixing the

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* The American "Eclectics" are charlatans, who nevertheless employ substances many of which are of undoubted value, and have received too little attention from the physician.

precipitate with an equal bulk of some inert powder. It was obtained from Tilden & Co. of New York, through Messrs Duncan & Flockhart of Edinburgh.

Experiment 27. Dog that had fasted seventeen hours. Weight 19 kilogrammes (fig. 27).—2 cc. bile and 2 cc. water injected into duodenum at *b*. Five grains of euonymin in the same fluid injected at *e*.

The irregularity in the biliary flow in this case was certainly owing to an irregularity in *secretion*, for the cannula was perfectly patent throughout the whole of the experiment. The irregularity did not consist in the bile being expelled in jets, as might have been expected had it been owing to contraction of the larger bile-ducts at intervals; but there was a rapid aud steady flow for some minutes, and then for a while it flowed much more slowly. This irregularity of secretion was probably in large measure due to unusual traction upon the bile-duct and liver during the introduction of the cannula, which in this case was much more difficult than usual. We have repeatedly observed that unless this part of the preliminary operation be conducted so as to very slightly disturb the bile-duct and its surroundings, the biliary secretion is rendered irregular. Nevertheless it is evident that in this case the euonymin stimulated the liver.

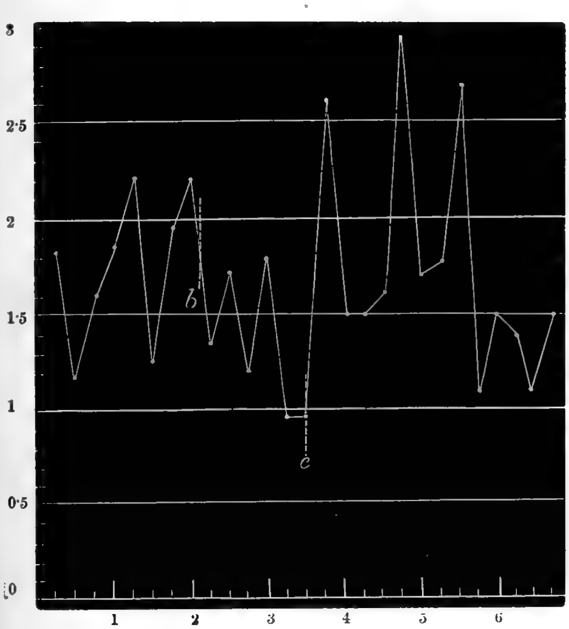

Fig. 27.—Secretion of bile before and after euonymin. 2 cc. bile and 2 cc. water injected into duodenum at *b*. 5 grains of euonymin, together with the above fluid, injected at *e*.

Experiment 27.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
1·82	
1·2	
1·6	
1·85	
2·2	
1·3	
1·95	
2·2	
b ——	
1·35	
1·7	
1·2	0·2578 cc.
1·8	
0·95	
0·95	
e ——	
2·6	
1·5	
1·5	
1·6	
2·95	0·4789 cc.
1·7	
1·75	
2·7	
1·1	
1·5	
1·4	
1·1	
1·5	

Necropsy.—There was very slight evidence of purgative action, but the mucous membrane of the upper fourth of the small intestine was much more vascular than usual.

Experiment 28. Dog that had fasted twenty-four hours. Weight 23·3 kilogrammes (fig. 28).—The unusually long fast resulted from the animal having refused to take food on the afternoon of the day preceding the experiment. It was probably owing to this circumstance that the secretion of bile was so low at the beginning of the experiment. 1·1 cc. bile and 3 cc. water injected into duodenum at *b*. The same with 5 grains of euonymin injected at *e*.

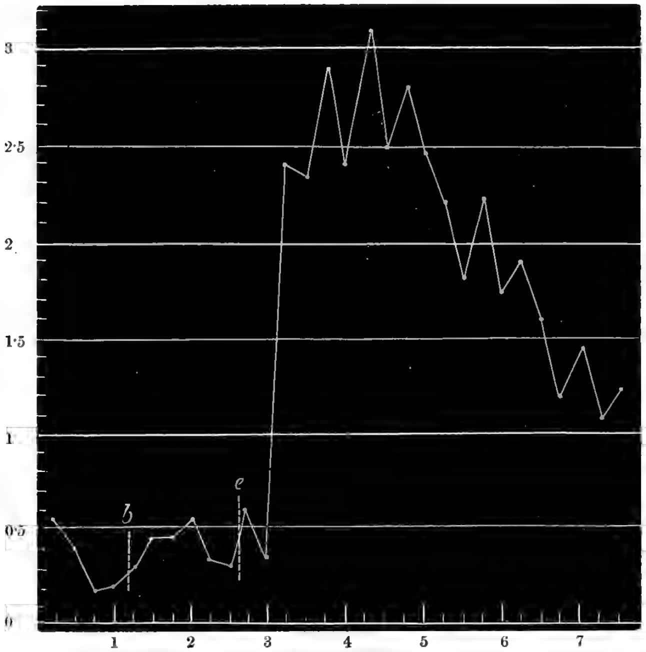

Fig. 28.—Secretion of bile before and after euonymin. 1·1 cc. bile and 3 cc. water injected into the duodenum at *b*. The same with 5 grains euonymin injected at *e*.

Experiment 28.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
0·55	
0·4	
0·2	
0·21	
0·3	
b ——	
0·45	
0·45	0·0708 cc.
0·55	
0·35	
0·3	
e ——	
0·6	
0·35	
2·4	
2·35	
2·9	0·4678 cc.
2·4	
3·1	
2·5	
2·8	
2·45	
2·25	
1·75	
2·25	
1·6	
1·85	
1·6	
1·2	
1·45	
1·1	
1·25	

Necropsy.—Stomach contracted, mucous membrane normal. The euonymin had extended along about a third of the small intestine. The mucous membrane of the upper third was extremely vascular. Mucous flakes were scattered over the surface. But notwithstanding the increased vascularity, the intestine at this part contained only a small quantity of a watery fluid. The remainder of the intestine was dry and contracted, without any signs of irritation.

TABLE XIII.

Euonymin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 27, .	5 with bile,	0·21	0·07 cc.	0·46 cc.
„ 28, .	5 „ „	0·26	0·25 cc.	0·47 cc.

Results of Experiments with Euonymin.—1. Five grains of euonymin, when mixed with a small quantity of bile and water, and placed in the duodenum, powerfully stimulated the liver. 2. Coincident with the marked action on the liver there was only a slight increase of intestinal secretion.

Experiments with Euonymin on Man.—In consequence of the powerful stimulation of the liver produced by euonymin in the above experiments, we were induced to make observations with it on the human subject in cases of biliousness, and we found the remedy of such value that it will, in consequence of these experiments, doubtless ere long be generally employed as a hepatic stimulant. Two grains made into a pill with conserve of roses, and taken at night, is a fair average dose for a man, though as much as five grains may be taken. A dose of two grains produces no sickness, headache, or other disagreeable sensation, and leaves no depression. But it must be remembered that while euonymin is a powerful hepatic, it is a feeble intestinal stimulant, and therefore it is well to follow it in the morning with some intestinal stimulant, such as two or three ounces Püllna water, or some other saline aperient. We are convinced from many observations that euonymin is particularly suited for cases in which the liver requires to be frequently stimulated.

ACTION OF RESINA IRIDIS OR "IRIDIN."

The root of the *Iris versicolor*, or American Blue Flag, is said by WOOD and BACHE (*Op.* x. p. 487) to possess cathartic, emetic, and diuretic properties. The American "Eclectics" have used, under the name of iridin or irisin, an oleo-resin prepared in the same way as euonymin (p. 170). The dose of this is 1–5 grains as a purgative. "It is thought to unite cholagogue and diuretic with aperient properties" (WOOD and BACHE, *loc. cit.*). An anonymous writer in the *Lancet* (August 30, 1862) states that "it is gentler in its action than podophyllin, and more reliable when a slight cholagogue action is required for a lengthened period." This statement, however, has been generally neglected, and the substance appears to be unknown to most persons.

The substance employed by us was obtained from Messrs Duncan & Flockhart of Edinburgh.

Experiment 29. Dog that had fasted seventeen hours. Weight 22·7 kilogrammes (fig. 29).—2 cc. bile and 3 cc. water injected into the duodenum at *b*. The same with 5 grains of iridin injected at *i*.

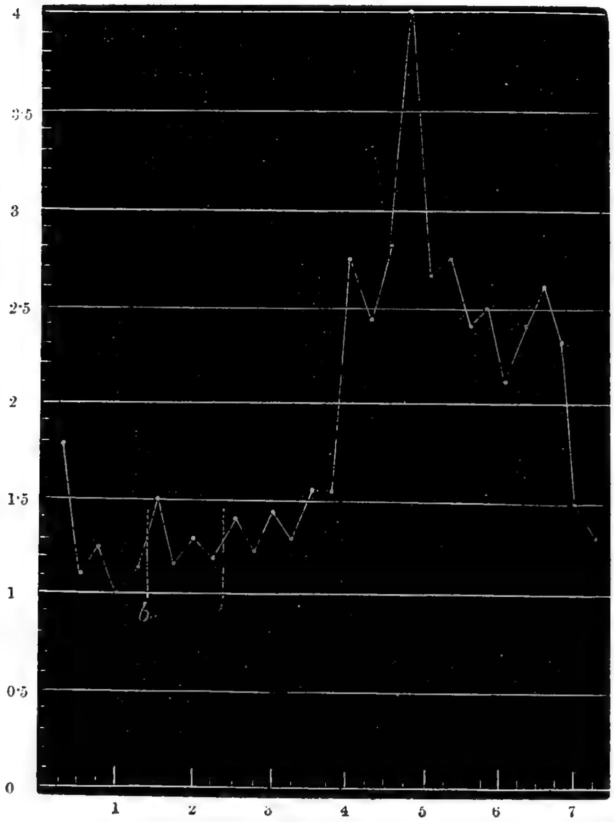

Fig. 29.—Secretion of bile before and after iridin. 2 cc. bile and 3 cc. water injected into the duodenum at *b*. 5 grains iridin in the same fluid injected at *i*.

Experiment 29.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
1·8	
1·1	
1·25	
1·0	
1·15	
b ——	
1·5	0·227 cc.
1·16	
1·3	
1·2	
i ——	
1·4	
1·25	
1·45	
1·3	
1·55	
1·55	
2·75	
2·45	
2·8	0·537 cc.
4·0	
2·65	
2·75	
2·4	
2·5	
2·1	
2·4	
2·6	
2·3	
1·5	
1·3	

Necropsy.—Stomach normal. Mucous membrane of upper two-thirds of small intestine rather more vascular than usual. This portion of the intestine contained 63 cc. of fluid, thus affording evidence of a decided purgative effect.

Experiment 30. Dog that had fasted eighteen hours. Weight 5.4 kilogrammes (fig. 30).—2 cc. bile and 2 cc. water injected into the duodenum at *b*. The same with 5 grains of iridin injected at *i*.

NECROPSY.—Stomach normal. There was increased vascularity of the mucous membrane of nearly the whole length of the small intestine. The redness was not very marked, but it was greater than in the previous experiment. There was decided purgation, the small intestine containing 87 cc. of fluid with abundant mucous flocculi.

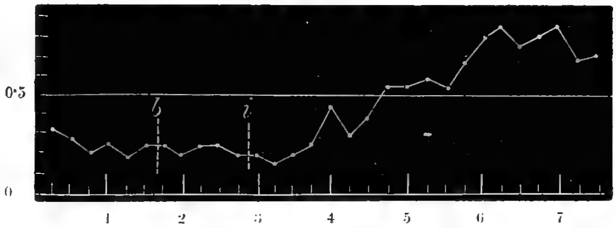

Fig. 30.—Secretion of bile before and after iridin. 2 cc. bile and 2 cc. water injected into the duodenum at *b*. 5 grains iridin in the same fluid injected at *i*.

Experiment 30.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·32		0·25	
0·3		0·45	
0·2		0·3	
0·25		0·4	
0·2		0·55	
0·25		0·55	
b——		0·6	
0·25	0·166 cc.	0·55	
0·2		0·7	
0·25		0·85	
0·25		0·9	0·638 cc.
0·2		0·8	
i——		0·85	
0·2		0·9	
0·15		0·7	
0·2		0·75	

Results of Experiments with Iridin.—1. Five grains of iridin when mixed with a little bile and water and placed in the duodenum very powerfully stimulated the liver. It is not so powerful as large doses (four grains) of podophyllin, but it is more powerful than euonymin, as is shown by the amount of bile secreted per kilogramme of dog; the hourly coefficients of secretion for the two euonymin experiments being 0·4789 cc. and 0·4678 cc., whereas in the iridin experiments they are 0·537 cc. and 0·638 cc. respectively. The high coefficient in the second iridin experiment probably resulted from a much smaller dog getting the same dose as in the first experiment, the smaller liver being thereby stimulated to do a proportionally greater amount of work. 2. Iridin is also a decided stimulant of the intestinal glands. Judging from these experiments, its irritant effects on the intestinal mucous membrane are decidedly less than those of podophyllin, while the purgative effects are greater than in the case of euonymin. The statement of the writer in the *Lancet* (above quoted) that in man "it is gentler in its action than podophyllin" is fully supported by these experiments.

TABLE XIV.

Iridin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 29, .	5 with bile,	0·22	0·22 cc.	0·53 cc.
„ 30, .	5 „	0·92	0·16 cc.	0·63 cc.

Experiments with Iridin on Man.—In consequence of the striking results of the above experiments, we have made many observations with iridin on the human subject, and it is certain that we have in this substance a remedy for functional hepatic derangement of such value that it will probably in due time be universally employed. As yet we have found four grains of iridin a certain remedy for biliousness. It may be made into a pill with conserve of roses and taken at bedtime. It produces no disagreeable sensations, and on awaking in the morning the yellow tongue is clean, and the headache and *malaise* are gone. As iridin, though a powerful hepatic, is not a powerful intestinal stimulant, it is well to give in the morning an ordinary mild saline aperient, such as Püllna water. Iridin is a more powerful excitant of the liver than euonymin, and a more powerful remedy for biliousness,* and is particularly suitable when the bilious attack is very pronounced, but we find that when taken two nights in succession it is apt to leave a somewhat depressed effect, and therefore it probably ought not to be taken more than once a week. Euonymin is therefore to be preferred when repeated stimulation of the liver is required; and further, observations which we have made on an elderly gentleman suffering from indolent liver and irritable prostate, convince us that iridin is a prostatic irritant, and that as euonymin produces no apparent effect on the prostate, it is to be preferred as a stimulant of the liver in cases of prostatic irritation. It will also be of practical importance to bear in mind that iridin and euonymin are both of them diuretics, iridin being the more powerful of the two.

ACTION OF RESINA LEPTANDRÆ OR "LEPTANDRIN."

"Leptandria" or "Leptandrin" is a resin prepared from the root of the American plant, *Leptandra virginica* or *Veronica virginica,* in the same manner as euonymin (p. 170). It is a remedy that has been much lauded by the

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* It is difficult to say what is the exact cause of biliousness, but it is certain that this condition is speedily cured by iridin and euonymin, and that both of these substances powerfully stimulate the liver, while they stimulate the intestine to only a moderate extent.

"Eclectics" as a cholagogue and tonic. As this remedy is now a good deal employed in the case of children, it seemed desirable to obtain more precise information regarding its mode of action. The dose for a man is ½–3 grains three or four times daily.

Experiment 31. Dog that had fasted eighteen hours. Weight 20·4 kilogrammes (fig. 31).—3 cc. bile and 3 cc. water injected into the duodenum at *b*. 6 grains leptandria in the same fluid injected at *e*. 12 grains leptandria in 2 cc. rectified spirit and 8 cc. water injected at *e′*.

Experiment 31.		Experiment 32.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·8		0·35	
0·85		0·2	
0·95		0·25	
0·85		0·3	
0·8		0·25	0·0839 cc.
b ——		0·3	
1·2	0·191 cc.	*e* ——	
0·95		0·55	
0·95		0·4	
e ——		0·45	
1·4		0·35	
1·3		0·55	
1·45		*e′* ——	
1·45	0·272 cc.	0·4	
1·35		0·55	
1·3		0·55	
1·2		0·5	
1·2		*e″* ——	
e′ ——		0·5	
1·45		0·7	
1·3		0·85	
1·45	0·274 cc.	1·2	
1·5		0·9	
1·35		0·9	
1·2		1·05	
1·1		1·0	
1·4		1·05	
1·25		0·95	
1·2		1·1	0·3167 cc.
		1·05	

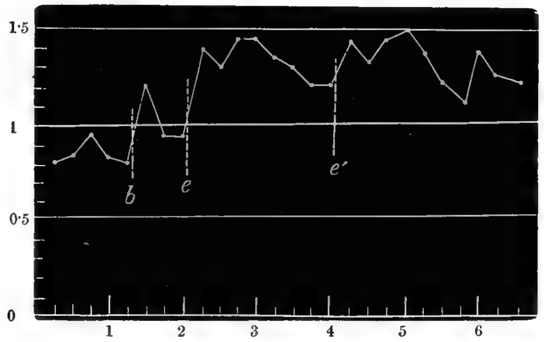

Fig. 31.—Secretion of bile before and after leptandria. 3 cc. bile and 3 cc. water injected into the duodenum at *b*. 6 grains leptandria in the same fluid injected at *e*. 12 grains leptandria in 2 cc. rectified spirit and 8 cc. water injected at *e′*.

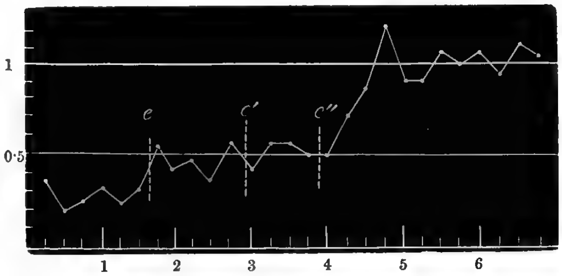

Fig. 32.—6 grains leptandria in 4 cc. water injected into the duodenum at *e*. 1½ cc. bile and 3 cc. water injected at *e′*. 12 grains leptandria in the same fluid injected at *e″*.

Experiment 32. Dog that had fasted eighteen hours. Weight 13·1 kilogrammes (fig. 32).—6 grains leptandria in 4 cc. water injected into the duodenum at *e*. 1½ cc. bile and 3 cc. water injected at *e′*. 12 grains leptandria in the same fluid injected at *e″*.

Necropsy.—Slightly increased vascularity of the mucous membrane of the upper half of the small intestine. There was slight purgation;—the upper half of the small intestine containing 37 cc. of a viscous fluid.

TABLE XV.

Leptandria.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 31, .	18 with bile,	0·88	0·191 cc.	0·274 cc.
„ 32, .	18 „	1·1	0·083 cc.	0·316 cc.

TABLE XVI.—*Composition of the Bile before and after Leptandria.*

Experiment 33.	Before.	After.
Water, ...	91·34	91·41
Bile-acids, pigments, cholesterin, fats, ...	6·64	6·60
Mucus, ...	0·95	0·92
Ash, ...	1·07	1·07
	100·00	100·00
Velocity of secretion per half hour, ...	1·9 cc.	2·5 cc.

It appears from this analysis that the bile secreted under the influence of leptandria retained its normal composition.

Results of Experiments with Leptandria.—Leptandria is a feeble hepatic and intestinal stimulant. Notwithstanding the large doses employed, the hourly coefficient of secretion did not rise above 0·316 cc. The bile has the normal composition. As in the case of other resinous matters, the absence of the biliary solvent from the duodenum greatly lessens the effect (Experiment 32).

ACTION OF RESINA SANGUINARIÆ, OR "SANGUINARIN."

Dr WOOD (*Op.* xi. p. 367) states that, "although the *Sanguinaria canadensis* has been used more or less for so many years, we are still without any really definite knowledge of its action. Little or nothing has been added to our knowledge since the papers by Dr TULLY in 1830, who stated that when given in small repeated doses it acts as a very decided cholagogue; and more recently it has been affirmed that it is also a stimulating expectorant. In full doses it is certainly a harsh emetic, and in overdoses, according to TULLY, it produces with the vomiting, burning at the stomach, faintness, vertigo, dimness of vision, general insensibility, coldness, extreme reduction of the force and frequency of the pulse, great prostration of the muscular strength, and sometimes a convulsive rigidity of the limbs." Dr WOOD states that he has never known of its employment except as a stimulant expectorant in obstinate bronchitis. Dr MOTHERSHEAD, of Indianapolis (quoted in *Op.* x. p. 741) however "speaks in the strongest terms of its efficacy as an excitant of the liver, when given in alterative doses." On the other hand, Professor THOMAS of Philadelphia (quoted in *Op.* x. p. 742), found the active principle sanguinarina to "have no effect of any kind directly on the liver" of man. "Sanguinarin" is, however, recommended by the American "Eclectics" in doses of $\frac{1}{4}$–1 grain as a hepatic alterative. The substance employed in the following experiments is a resin prepared in the same manner as euonymin (see p. 170).

Experiment 33. Dog that had fasted seventeen hours. Weight 27·7 kilogammes (fig. 33).—2 cc. bile and 2·5 cc. water injected into the duodenum at *b*. 1 grain sanguinarin in the same fluid injected at *s*. 2 grains sanguinarin in the same fluid injected at *s′*.

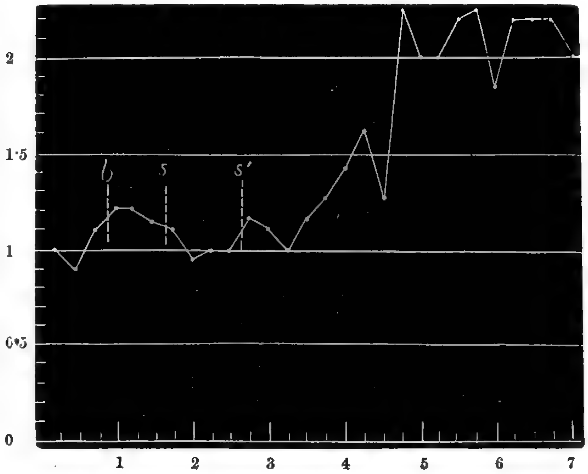

Fig. 33.—Secretion of bile before and after sanguinarin. 2 cc. bile and 2·5 cc. water injected into the duodenum at *b*. 1 grain sanguinarin in the same fluid injected at *s*. 2 grains sanguinarin in the same fluid injected at *s′*.

Experiment 33.

	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
	cc.		cc.	
	1·0		1·15	
	0·9		1·25	
	1·1		1·4	
b			1·6	
	1·2	0·1678 cc.	1·25	
	1·2		2·22	
	1·15		2·0	
s			2·0	
	1·1		2·2	0·3039 cc.
	0·95		2·22	
	1·0		1·85	
	1·0		2·2	
s′			2·2	
	1·15		2·2	
	1·12		2·0	
	1·0			

NECROPSY.—Mucous membrane of upper two-thirds of small intestine was of a clear claret colour, here and there it was marked by brownish patches of a size varying from that of a sixpence to that of a half-crown. There were 35 cc. of a thick brown fluid in the small intestine. The brown colour was apparently owing to the presence of the sanguinarin, a substance of a brownish-red colour.

Experiment 34. Dog that had fasted seventeen hours. Weight 20 kilogrammes (fig. 34).—2 cc. bile and 3 cc. water injected into duodenum at *b*. The same with 1 grain sanguinarin injected at *s*.

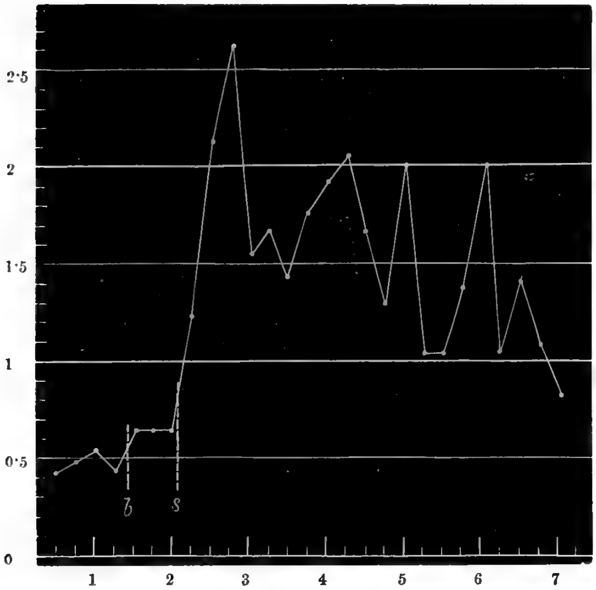

Fig. 34.—Secretion of bile before and after sanguinarin. 2 cc. bile and 3 cc. water injected into the duodenum at *b*. 1 grain sanguinarin in the same fluid injected at *s*.

Experiment 34.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.	
0·41	
0·49	
0·52	
0·45	
b ——	
0·65	0·12 cc.
0·65	
0·65	
s ——	
1·25	0·401 cc.
2·15	
2·65	
1·55	
1·7	
1·45	
1·8	
1·9	
2·02	
1·7	
1·3	
2·0	
1·05	
1·05	
1·35	
2·0	
1·05	
1·4	
1·1	
0·8	

NECROPSY.—Vascularity of the mucous membrane of upper half of small intestine somewhat increased. Considerable evidence of purgative action in upper half of small intestine. Contents of a viscid mucous character.

TABLE XVII.

Sanguinarin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 33, .	1, with bile	0·05	0·12 cc.	0·30 cc.
„ 34, .	3, „	0·11	0·16 cc.	0·40 cc.

TABLE XVII.—*Composition of Bile before and after Sanguinarin.*

Experiment 33.	Before.	After.
Water,	90·09	91·41
Bile-acids, pigments, cholesterin, fats,	7·38	6·57
Mucus,	1·04	0·90
Ash,	1·49	1·12
	100·00	100·00
Velocity of secretion per half hour,	2·4 cc.	4·25 cc.

It appears from this analysis that under the influence of sanguinarin the bile becomes more watery, nevertheless the velocity of secretion having been nearly doubled by this agent, it is evident that the liver secreted more biliary matter.

Results of Experiments with Sanguinarin.—1. In one experiment three grains, in another experiment one grain, of sanguinarin when mixed with a small quantity of bile and water and placed in the duodenum powerfully stimulated the liver. 2. It rendered the bile more watery, nevertheless it caused the liver to secrete more biliary matter in a given time. 3. The secretion of the intestinal glands was slightly increased by these doses. These results show that the statements of TULLY and MOTHERSHEAD ought not to be treated with indifference and neglect, as they appear to be, in practical medicine.

ACTION OF IPECACUAN.

As is well known, ipecacuan is regarded as almost a specific remedy in certain cases of dysentery. It is stated that it gives rise to evacuations containing a large quantity of bile. The manner in which it does this is not definitely known. Some maintain that it permits of biliary discharge by relieving spasm of the bile-ducts. The following experiments, undertaken at the desire of Sir ROBERT CHRISTISON, prove beyond a doubt that this substance is a powerful stimulant of the hepatic secreting apparatus. The maximum dose for a man is 60 grains.

Experiment 35. Dog that had fasted eighteen hours. Weight 15 kilogrammes (fig. 35).—2 cc. bile and 3 cc. water injected into the duodenum at *b*. 60 grains ipecacuan powder in the same fluid injected at *i*.

NECROPSY.—The ipecacuan had extended along the upper half of the small intestine, the mucous membrane of which portion was covered with thick white mucus. No purgation.

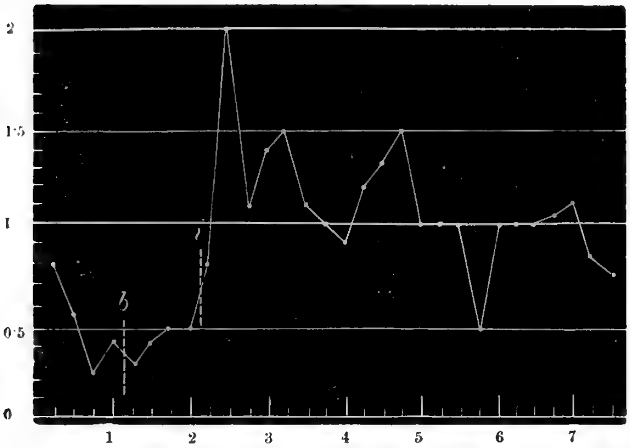

Fig. 35. Secretion of bile before and after ipecacuan. 2 cc. bile and 3 cc. water injected into the duodenum at *b*. 60 grains ipecacuan powder in the same fluid injected at *i*.

Experiment 35.		
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.
cc.		1·0
0·8		0·9
0·55		1·2
0·25		1·3
0·4		1·5
b ——		1·0
0·3	0·113 cc.	1·0
0·4		1·0
0·5		0·5
0·5		1·0
i ——		1·0
0·8		1·0
2·0	0·4 cc.	1·05
1·1		1·1
1·4		0·8
1·5		0·7
1·1		

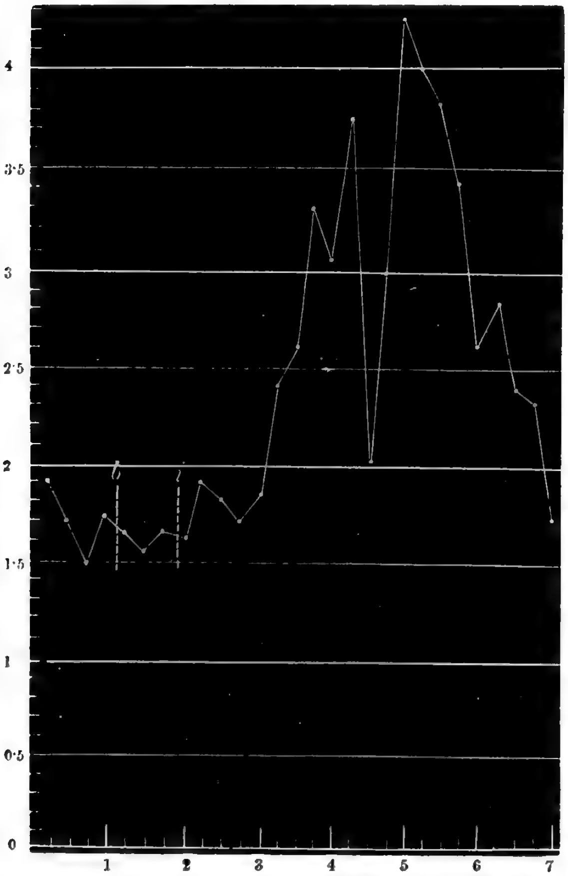

Fig. 36. Secretion of bile before and after ipecacuan. 2 cc. bile and 5 cc. water injected into the duodenum at *b*. The same fluid with 60 grains ipecacuan powder injected at *i*.

Experiment 36.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
1·9	
1·7	
1·5	
1·7	0·24 cc.
b ——	
1·65	
1·55	
1·65	
i ——	
1·6	
1·9	
1·8	
1·7	
1·85	
2·4	
2·6	
3·3	
3·05	
3·75	
2·02	
3·0	0·555 cc.
4·25	
4·0	
3·85	
3·42	
2·6	
2·8	
2·35	
2·3	
1·7	

Experiment 36. Dog that had fasted eighteen hours. Weight 27·2 kilogrammes (fig. 36).—2 cc. bile and 5 cc. water injected into the duodenum at *b*. The same fluid with 60 grains ipecacuan powder injected at *i*.

NECROPSY.—Stomach normal. The ipecacuan extended along the upper two-thirds of the small intestine, the mucous membrane of which exhibited a slight increase of vascularity, and was covered with thick mucus, but there was no purgation.

Even in much smaller doses, however, ipecacuan excites the liver, as is shown by the two following experiments.

Experiment 37. Dog that had fasted eighteen hours. Weight 6·1 kilogrammes (fig. 37).—1·5 cc. bile and 2 cc. water injected into the duodenum at *b*. The same fluid with 3 grains of ipecacuan powder injected at *i*.

Experiment 37.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.		*i* ——	
0·2		0·4	
0·2		0·25	
0·2		0·3	
0·25		0·7	0·385 cc.
0·3		0·7	
0·25		0·45	
0·3		0·5	
0·3		0·7	
0·2		0·7	
b ——		0·35	
0·25	0·18 cc.	0·45	
0·25		0·5	
0·3		0·45	
0·3		0·4	

Experiment 38.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.		0·9	
0·3		0·6	
0·2		0·6	
0·25		0·9	0·506 cc.
0·25		1·0	
0·25		0·8	
b ——		1·15	
0·3	0·186 cc.	0·55	
0·35		0·45	
0·32		0·5	
0·3		0·35	
i ——		0·4	
0·45		0·3	
0·6			

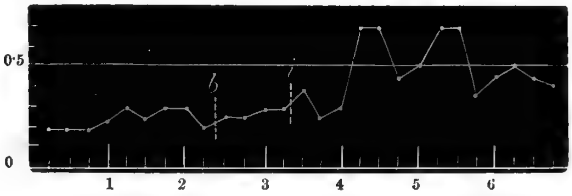

Fig. 37. Secretion of bile before and after ipecacuan. 1·5 cc. bile and 2 cc. water injected into the duodenum at *b*. The same fluid with 3 grains of ipecacuan powder injected at *i*.

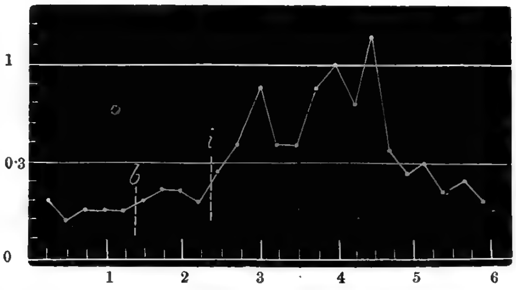

Fig. 38.—Secretion of bile before and after ipecacuan. 1·5 cc. bile and 2 cc. water injected into duodenum at *b*. 3 grains ipecacuan powder in the same fluid injected at *i*

NECROPSY.—Thick mucus covering the mucous membrane of upper fourth of small intestine. No purgation.

Experiment 38. Dog that had fasted seventeen hours. Weight 6·8 kilogrammes (fig. 38).—1·5 cc. bile and 2 cc. water injected into duodenum at *b*. 3 grains ipecacuan powder in the same fluid injected at *i*.

NECROPSY.—The appearances of the intestine were similar to those observed in the preceding experiment.

TABLE XVIII.

Ipecacuan.	Total Dose in Grains.	Grains per Kilogramme of Body-Weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 36, .	60 with bile,	2·2	0·24 cc.	0·55
„ 37, .	3 „ „	0·49	0·18 cc.	0·38

TABLE XIX.—*Composition of the Bile before and after Ipecacuan.*

Experiment 36.	Before.	After.
Water, ...	89·631	89·77
Bile acids, pigments, cholesterin, fats, ...	8·13	8·129
Mucus, ...	1·01	0·87
Ash, ...	1·229	1·231
	100·000	100·000
Velocity of secretion per half hour, ...	3·2 cc.	6·35 cc.

TABLE XX.

Experiment 38.	Before.	After.
Water, ...	91·32	91·51
Bile-acids, pigments, cholesterin, fats, ...	6·73	6·73
Mucus, ...	0·98	0·79
Ash, ...	0·97	0·97
	100·00	100·00
Velocity of secretion per half hour, ...	0·65 cc.	1·9 cc.

These analyses show that, notwithstanding the acceleration of secretion by ipecacuan, the percentage amount of the special biliary constituents remains unchanged.

Results of Experiments with Ipecacuan.—1. Sixty grains of powdered ipecacuan mixed with a small quantity of bile and placed in the duodenum powerfully stimulated the liver. Even three grains had an effect on a dog weighing 6·8 kilogrammes very nearly as great as the effect of sixty grains on a dog weighing 27·2 kilogrammes; the amount of bile secreted per kilogramme of dog being nearly the same in both cases. 2. The bile secreted under its influence was of normal composition as regards the biliary matter proper. 3. No purgative effect was produced, but there was an increased secretion of mucus in the small intestine. The composition of the bile did not afford any evidence of an increased secretion of mucus having taken place from the glands of the bile-ducts. The sickness which ipecacuan is apt to induce will prevent its use as a hepatic stimulant in ordinary cases.

The increased biliary flow that followed ipecacuan could not in these experiments be ascribed to any relaxation of "spasm of the bile-ducts," for that no such thing existed was clearly shown by the free flow of the bile before the substance was given. Nor could it be owing to contraction of the gall-bladder, for the cystic duct was clamped. Nor could it be ascribed to contraction of the bile-ducts, for the increased flow was far too prolonged to be attributable to any such cause. It is therefore certain that this substance, like the others, has the power of stimulating the *secreting* apparatus of the liver. This being now proved as regards the dog, it can scarcely be doubted that the *modus operandi* is the same in man. The results of these experiments will therefore lead to new speculations regarding the pathology of dysentery; for *every step towards greater accuracy of knowledge regarding the modus operandi of any therapeutic agent is certainly calculated to advance our knowledge of the true nature of the pathological condition that is relieved or cured by it.*

ACTION OF COLOCYNTH.

Colocynth and jalap are well known intestinal stimulants, but nothing is said in works on Materia Medica regarding their influence on the discharge of bile. RÖHRIG, however (*Op.* vi. p. 240), investigated their action in the dog, and found that they excite the liver. He thought them so powerful that he placed them next to croton oil in importance. We have already pointed out the faultiness of RÖHRIG's method, and have shown that croton oil is scarcely worthy of being classed amongst chologogues. It seemed therefore desirable that we should experiment with colocynth and jalap in order to have results comparable with our experiments on other substances. The maximum dose of colocynth pulp for a man is eight grains.

Experiment 39. Dog that had fasted sixteen hours. Weight 26·3 kilogrammes (fig. 39).—2 cc. bile and 2 cc. water injected into the duodenum at *b*. The same fluid with 7 grains of powdered colocynth pulp injected at *c*. The same dose repeated at *c′*.

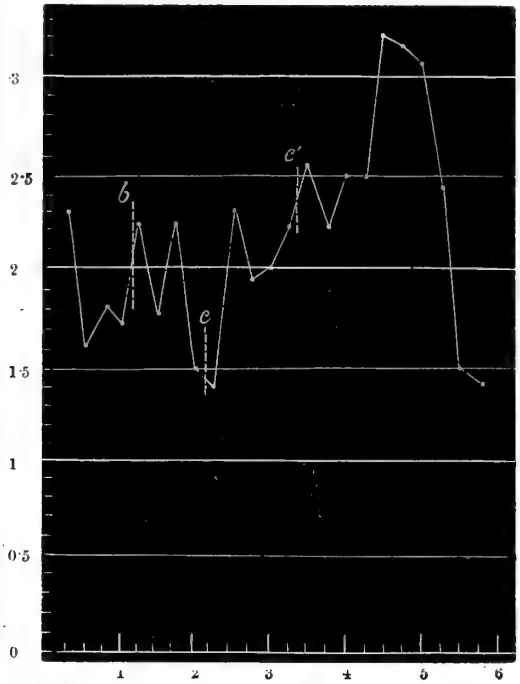

Fig. 39. Secretion of bile before and after colocynth. 2 cc. bile and 2 cc. water injected into the duodenum at *b*. The same fluid with 7 grains of powdered colocynth pulp injected at *c*. The same dose repeated at *c′*.

Experiment 39.		
	Secretion of bile 15″.	Secretion of bile per kilogramme of dog: per hour.
	cc.	
	2.3	
	1·6	
	1·8	
b		
	1·7	
	2·2	0·2908 cc.
	1·75	
	2·2	
	1·5	
c		
	1·4	
	2·3	
	1·95	
	2·0	
	2·2	
c′		
	2·55	
	2·2	
	2·5	
	2·5	0·452 cc.
	3·2	
	3·15	
	3·05	
	2·45	
	1·5	
	1·4	

NECROPSY.—Gastric mucous membrane very vascular. The mucous membrane of the small intestine was intensely vascular throughout its entire length. There was evidence of powerful purgation—the small intestine containing 82 cc. of fluid.

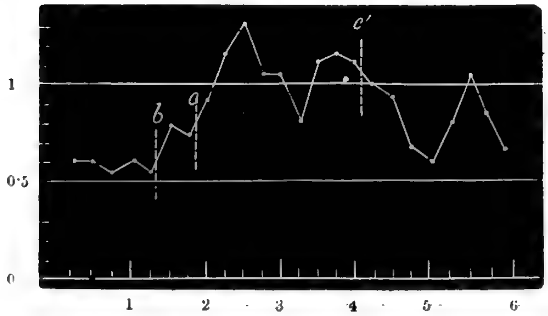

Fig. 40. Secretion of bile before and after colocynth. 3 cc. bile and 3 cc. water injected into the duodenum at *b*. The same with 7 grains colocynth injected at *c*. The same repeated at *c′*.

Experiment 40.					
	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.		Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
	cc.			cc.	
	0·6			0·8	
	0·6			1·1	
	0·55	0·165 cc.		1·15	
	0·6			1·1	
	0·55		*c′*		
b				1·0	
	0·8			0·95	
	0·75			0·65	
c				0·6	
	0·9			0·8	
	1·15	0·279 cc.		1·05	
	1·3			0·85	
	1·05			0·65	
	1·05				

Experiment 40. Dog that had fasted sixteen hours. Weight 16·3 kilogrammes (fig. 40).—3 cc. bile and 3 cc. water injected into the duodenum at *b*. The same with 7 grains colocynth injected at *c*. The same repeated at *c'*.

NECROPSY.—There was increased vascularity throughout the whole length of the mucous membrane of the small intestine, especially marked in the upper part. There was considerable evidence of purgation.

TABLE XXI.

Colocynth.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 39, .	14 with bile,	0·53	0·29 cc.	0·45 cc.
„ 40, .	7 „	0·4	0·16 cc.	0·27 cc.

In Experiment 40, the pulse became very weak towards the close of the experiment, and it may be that this weakness rendered the effect of the colocynth upon the liver less than it otherwise might have been. Be this as it may, we did not think it necessary to perform another experiment, for the first experiment with this substance may be regarded as sufficient.

TABLE XXII.—*Composition of the Bile before and after Colocynth.*

Experiment 39.	Before.	After.
Water, ...	92·99	94·13
Bile-acids, pigments, cholesterin, fats, ...	5·49	4·70
Mucus, ...	0·90	0·70
Ash, ...	0·62	0·47
	100·00	100·00
Velocity of secretion per half hour, ...	3·4 cc.	6·35 cc.

The analysis shows that colocynth renders the bile more watery, but it is evident from the increased velocity of secretion that it compels the liver to secrete more of the biliary solids proper.

Results of Experiments with Colocynth.—Colocynth is, in large doses, a powerful hepatic, as well as intestinal stimulant. Though rendering the bile more watery, it increases the secretion of biliary matter.

Action of Jalap.

What is known of the action of jalap on the liver has been already referred to under colocynth. The maximum dose of jalap powder for a man is 30 grains.

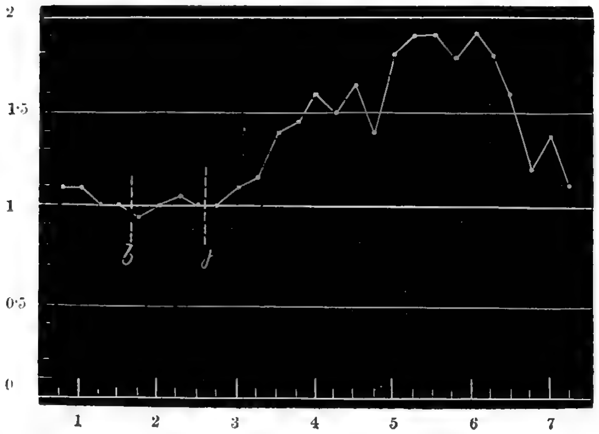

Fig. 41.—Secretion of bile before and after jalap. 2·5 cc. bile and 2·5 cc. water injected into the duodenum at *b*. 30 grains of jalap powder in the same fluid injected at *j*.

Experiment 41.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.		cc.	
1·1		1·6	
1·1		1·5	
1·0		1·65	
1·0		1·4	
b ——		1·8	
0·95		1·9	
1·0		1·9	
1·05	0·16 cc.	1·8	0·296 cc.
1·0		1·9	
j ——		1·8	
1·0		1·6	
1·1		1·2	
1·15		1·4	
1·4		1·1	
1·45			

Experiment 41. Dog that had fasted seventeen hours. Weight 25 kilogrammes (fig. 41).—2·5 cc. bile and 2·5 cc. water injected into the duodenum at *b*. 30 grains of jalap powder in the same fluid injected at *j*.

TABLE XXIII.

Jalap.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 41, .	30 with bile,	1·2	0·16 cc.	0·29 cc.
" 42, .	40 "	3·2	0·17 cc.	0·35 cc.

TABLE XXIV.—*Composition of the Bile before and after Jalap.*

Experiment 41.	Before.	After.
Water, ...	89·31	89·75
Bile-acids, pigments, cholesterin, fats, ...	8·41	8·05
Mucus, ...	0·93	0·87
Ash, ...	1·35	1·33
	100·00	100·00
Velocity of secretion per half-hour, ...	2·1 cc.	3·7 cc.

Necropsy.—The jalap had extended along about four-fifths of the small intestine, the mucous membrane of which was more vascular than usual, especially at the lower part of the duodenum. The purgative effect was considerable—there being 64 cc. of fluid in the intestine. The fluid was of a very watery character.

Experiment 42. Dog that had fasted twenty-two hours. Weight 12·3 kilogrammes (fig. 42).—2 cc. bile and 3 cc. water injected into duodenum at *b*. 20 grains jalap powder in the same fluid injected at *j*, *j′*, and *j″*.

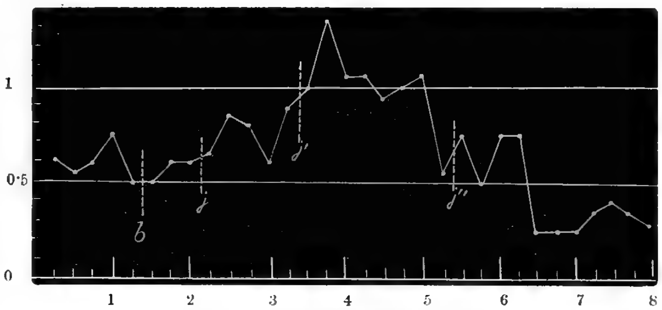

Fig. 42.—Secretion of bile before and after jalap. 2 cc. bile and 3 cc. water injected into duodenum at *b*. 20 grains jalap powder in the same fluid injected at *j*, *j′*, and *j″*.

The fall of the bile-secretion towards the close of the experiment is only another illustration of the fact often witnessed by us—*that severe purgation diminishes the secretion of bile.*

Necropsy.—20 cc. of fluid had been injected into the duodenum, much of which had probably been absorbed; the small intestine, however, contained in its upper third 117 cc. of watery fluid, showing that a profuse purgative action was taking place. The jalap had extended along only a third of the small intestine.

The analysis shows that although jalap renders the bile more watery, it so increases the velocity of secretion that more biliary matter is secreted in a given time.

Experiment 42.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·6		1·05	0·357 cc.
0·55		1·05	
0·6		0·95	
0·75		1·0	
0·5		1·05	
b ——		0·55	
0·5	0·178 cc.	*j″* ——	
0·6		0·75	
0·6		0·5	
j ——		0·75	
0·65		0·75	
0·85		0·25	
0·8		0·25	
0·6		0·25	
0·9		0·35	0·113 cc.
j′ ——		0·4	
1·0		0·35	
1·35	0·357 cc.	0·3	

Results of Experiments with Jalap.—1. Jalap is a hepatic stimulant of considerable power. It renders the bile more watery, but at the same time increases the secretion of biliary matter. 2. Its effect on the liver is however far less notable than its effects on the intestinal glands. Its hydragogue cathartic effects were fully manifested in these experiments.

ACTION OF TARAXACUM.

There exists a vague idea that taraxacum has some influence on the liver. It is stated that it is "supposed to modify and increase its secretion" (*Op.* viii. p. 295), but it is generally felt that its action is extremely doubtful.

Experiment 43. Middle-sized dog that had fasted twenty-four hours.—180 grains of solid extract of taraxacum in 25 cc. water were injected into the duodenum (*t*, fig. 43), and, two hours after this, 120 grains in the same quantity of water were injected (*t'*). After both doses there was a greater increase in the biliary secretion than was at all likely to have been caused by the same quantity of water. (*See* Experiment 7.)

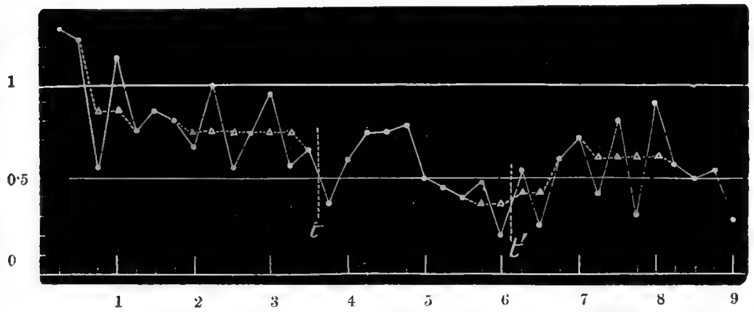

Fig. 43.—Secretion of bile before and after taraxacum. *t*, 180 grains ; *t'*, 120 grains of solid extract of taraxacum in 25 cc. of water were injected into the duodenum. (The triangles and dotted lines indicate the *mean* of the high and low readings in order that a conclusion regarding the effect of the substance may be more easily arrived at.)

NECROPSY.—The taraxacum had passed along nearly the whole length of the small intestine. Most of the fluid had been absorbed. There was no evidence of purgative action.

Experiment 43A. Small dog that had fasted eighteen hours.—120 grains of solid extract of taraxacum in 15 cc. of water were injected into the duodenum (*t*, fig. 43A), and this dose was repeated in two-and-a-half hours. The increase of the biliary secretion after the second dose was trivial; but after the first it was considerable, though of short duration. An examination of the intestine at death revealed no purgative action.

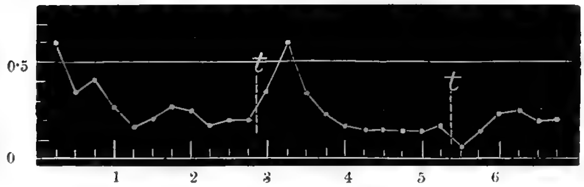

Fig. 43A.—Secretion of bile before and after taraxacum. 120 grains of solid extract of taraxacum in 15 cc. of water injected into the duodenum at *t* and *t'*.

From these experiments it may be concluded that taraxacum is a very feeble hepatic stimulant, a conclusion that is in harmony with clinical experience, although the observations on man—from the nature of the case—have yielded nothing perfectly definite. We think it unnecessary to detail these two experiments more fully.

ACTION OF NITRO-HYDROCHLORIC ACID.

The dilute nitro-hydrochloric acid employed by us was prepared by mixing 3 cc. nitric acid with 4 cc. hydrochloric acid, and after an interval of twenty-four hours, adding 25 cc. water ("British Pharmacopœia"). The dose for a man is from 5 to 20 minims.

The employment of this substance in hepatic disorder was first recommended by Dr Scott of Bombay, who used it largely in congestion of the liver. It was administered as a foot-bath, and also internally. Its effects, however, were by some held to be so doubtful, that its use appears to have been abandoned for a time (Christison, *Op.* xii. p. 41). Annesley, Martin, and others—experienced in the diseases of India—have, however, supported the opinion held by Scott. Wood (*Op.* xi. p. 88) maintains, from his own observation, that it increases the flow of the bile.

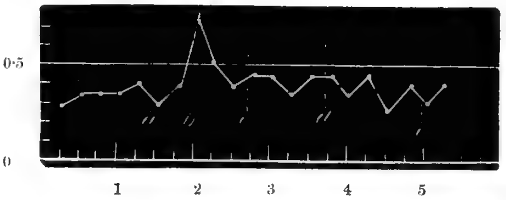

Fig. 44.—Secretion of bile before and after nitro-hydrochloric acid. 20 cc. water injected into duodenum at *a*. The same with 20 minims dilute nitro-hydrochloric acid injected at *b*, *c*, *d*, and *e*.

Experiment 44. A small dog (weight not ascertained) that had fasted seventeen hours (fig. 44).—20 cc. water injected into duodenum at *a*. The same with 20 minims dilute nitro-hydrochloric acid injected at *b*, *c*, *d*, and *e*.

Necropsy.—The duodenal mucous membrane was slightly congested. There was no evidence of purgation.

Experiment 44a. Dog that had fasted seventeeen hours. Weight 17·7 kilogrammes (fig. 44a).—40 minims dilute nitro-hydrochloric acid in 8 cc. water injected into duodenum at *a*, and again at *a′*.

Experiment 44a.		
	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
	cc.	
	0·55	0·117 cc.
	0·40	
	0·50	
	0·65	
a	——	
	1·00	
	0·95	
	1·05	
	1·10	
	1·40	
	1·45	
	1·55	
	1·60	
	1·40	
	1·50	0·392 cc.
	2·20	
	1·72	
	1·62	
	1·45	
a′	——	
	1·50	
	1·35	
	0·95	

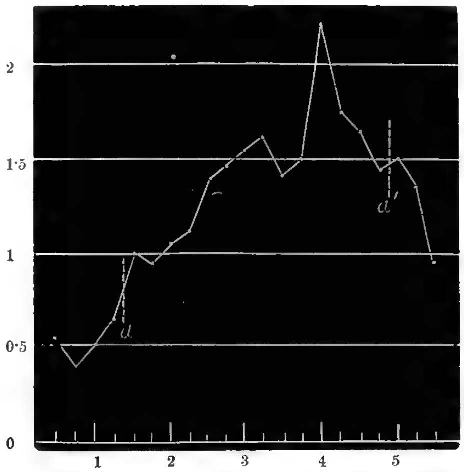

Fig. 44a.—Secretion of bile before and after nitro-hydrochloric acid. 40 minims dilute nitro-hydrochloric acid in 8 cc. of water injected into duodenum at *a*, and again at *a′*.

NECROPSY.—There was slight congestion of the upper part of the small intestine to the extent of about 10 inches. In the duodenum the mucous membrane had a yellowish-grey appearance, as if it had been slightly corroded by an acid. There was no evidence of any purgative effect.

Results of Experiments with Nitro-hydrochloric Acid.—The positive effect of the acid in Experiment 44A is in remarkable contrast to the negative result observed in Experiment 44. In consequence of the positive result in the former case, and seeing that it completely agrees with observations on man, we did not think it necessary to perform another experiment. In view of the positive effect in 44A, we do not attach any importance to the negative result of Experiment 44; for the animal was a small one, and in such cases we have found that undoubted cholagogues sometimes fail to act. It is proved, then, that dilute nitro-hydrochloric acid is a hepatic stimulant of considerable power.

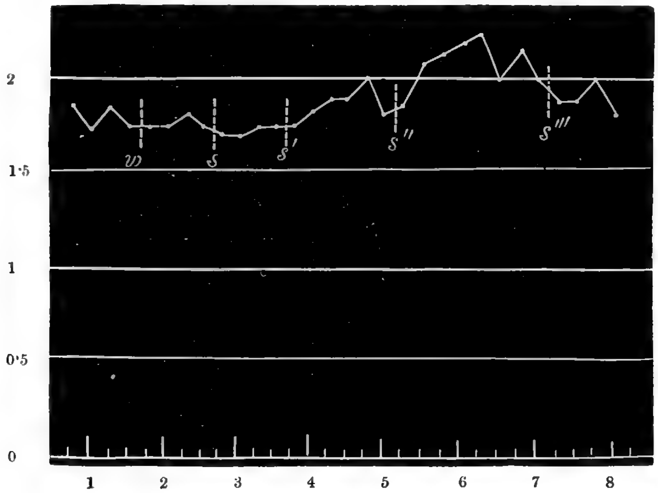

Fig. 45.—Secretion of bile before and after sodium chloride. 10 cc. water injected into duodenum at *w*. The same with 120 grains sodium chloride injected at *s*, *s*′, *s*″, *s*‴ (480 grains given in all).

Experiment 45.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·82		1·90	0·306 cc.
1·72		2·00	
1·82		1·80	
1·72		*s*″ ——	
w ——		1·85	
1·72	0·28 cc.	2·10	0·346 cc.
1·75		2·15	
1·80		2·20	
1·75		2·22	
s ——		2·00	
1·70		2·15	
1·70		2·00	
1·75		*s*‴ ——	
1·75		1·90	
s′ ——		1·90	
1·75		2·00	
1·85	0·306 cc.	1·80	
1·90			

ACTION OF SODIUM CHLORIDE.

Sodium chloride is a cathartic when given in doses of 120 to 240 grains. It is not stated to be a cholagogue, but as it is contained in considerable quantity in the mineral waters of Carlsbad, Ems, Friedrichshall, that have a reputation in abnormal conditions of the liver, we thought it desirable to test its action on this organ.

Experiment 45. Dog that had fasted eighteen hours. Weight 25 kilogrammes (fig. 45).—10 cc. water injected into duodenum at *w*. The same with 120 grains sodium chloride injected at *s*, *s*′, *s*″, *s*‴ (480 grains given in all).

Necropsy.—The small intestine contained 203 cc. of fluid, with numerous mucous flakes. As only 50 cc. of fluid had been injected, decided purgative action had taken place. The vascularity of the mucous membrane was slightly increased.

Result of Experiment with Sodium Chloride.—Inasmuch as the first three doses of sodium chloride, amounting in the aggregate to 360 grains, produced scarcely any effect on the secretion of bile, it may be concluded that this substance is a very feeble hepatic stimulant. Another experiment did not appear to be required.

ACTION OF SODIUM AND POTASSIUM TARTRATE.

Rochelle salt is well known as an intestinal stimulant, but its action on the liver has not hitherto been pointed out. The dose for a man is 120 to 240 grains.

Experiment 46. Dog that had fasted seventeen hours. Weight 5·2 kilogrammes (fig. 46).—10 cc. water injected into duodenum at *w*. The same with 60 grains Rochelle salt injected at *r*, *r′*, *r″*, and *r‴* (240 grains given in all).

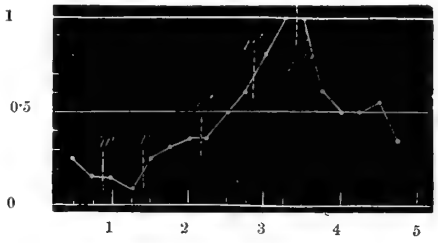

Fig. 46.—Secretion of bile before and after tartrate of potash and soda. 10 cc. water injected into duodenum at *w*. The same with 60 grains Rochelle salt injected at *r*, *r′*, *r″*, *r‴* (240 grains given in all).

No Necropsy.

Considering the small size of this animal, the exciting effect of the salt on the liver was very remarkable, the secretion of bile per kilogramme of body-weight per hour being raised to 0·653 cc. The fall in the secretion towards the close of the experiment was doubtless owing to purgative action taking place.

Experiment 46.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·25		0·50	
0·15		0·60	
w ——	0·115 cc.	*r″* ——	
0·15		0·80	
0·05		1·00	
r ——		*r‴* ——	0·653 cc.
0·25		1·00	
0·30		0·60	
0·35		0·50	
r′ ——		0·55	
0·35		0·35	

Experiment 46A. — Dog that had fasted twenty hours. Weight 12·5 kilogrammes (fig. 46A).—3 cc. bile and 55 cc. water heated to 37° C. injected into duodenum at *b*. The same with 463 grains Rochelle salt heated to 37° C. injected at *r*.

Necropsy.—Small intestine contained 130 cc. of a clear mucous fluid.

Mucous membrane of small intestine exhibited a slightly increased vascularity.

Results of Experiments with Rochelle Salt.—It is certainly a hepatic stimulant. Experiment 46 shows what a rapid secretion of bile it called forth in a liver that was nearly passive before it was given. The effect was by no means so remarkable in Experiment 46A, where the liver was relatively more active before the substance was given. Probably the latter affords a better general indication than the former of the power of this substance as a hepatic stimulant, and it must be remembered that in both cases, especially in the first, considering the size of the animals as compared with man, the doses were large; so that, on the whole, it may be anticipated that observations on man—now that we specially direct attention to the matter—will show that this substance stimulates the liver, but not powerfully.

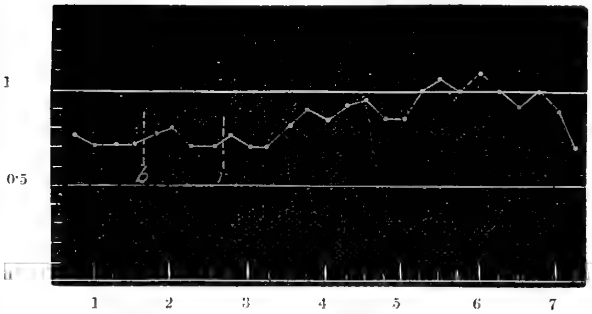

Fig. 46A.—Secretion of bile before and after Rochelle salt. 3 cc. bile and 55 cc. water heated to 37° C. injected into duodenum at *b*. The same with 463 grains Rochelle salt heated to 37° C. injected at *r*.

Experiment 46A.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·75		0·85	
0·70		0·90	
0·70		0·95	
0·70		0·85	
b ——		0·85	
0·75	0·236 cc.	1·00	0·332 cc.
0·80		1·05	
0·70		1·00	
0·70		1·10	
r ——		1·00	
0·75		0·90	
0·70		1·00	
0·70		0·90	
0·80		0·70	
0·90			

Table XXV.

Rochelle Salt.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 46, .	240	46·1	0·115 cc.	0·653 cc.
Experiment 46A, .	463	37·2	0·236 cc.	0·332 cc.

ACTION OF SODIUM PHOSPHATE.

Sodium phosphate is described in the text-books as a mild saline purgative; nothing being said about its action as a cholagogue. Professor STEPHENSON of Aberdeen (*Op.* xiii.), however, has found it specially useful for children when there is a deficiency of bile in the discharges. The dose as a purgative for a man is 120 to 480 grains.

Experiment 47. Dog that had fasted twenty hours. Weight 26·9 kilogrammes (fig. 47).—77 grains in 15 cc. water injected into duodenum at *s*, and 124 grains in 25 cc. water injected at *s′*.

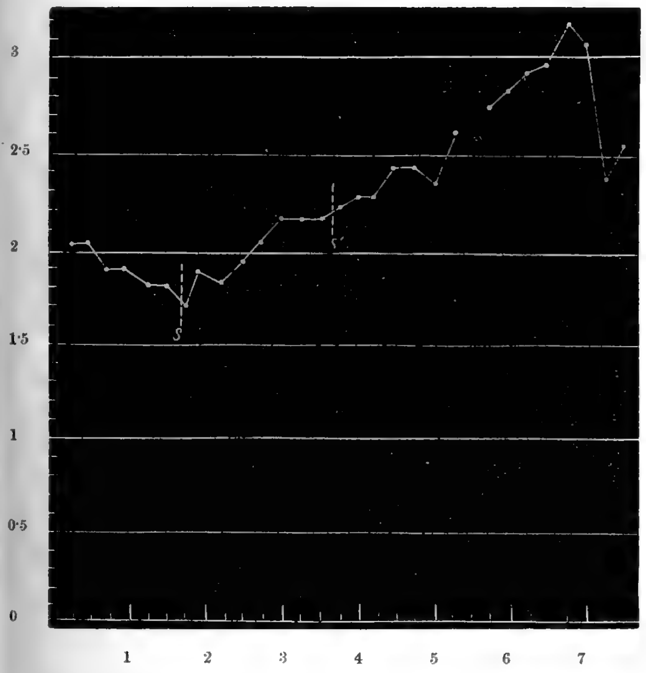

Fig. 47.—Secretion of bile before and after sodium phosphate. 77 grains in 15 cc. water injected into duodenum at *s*, and 124 grains in 25 cc. water injected at *s′*.

Experiment 47.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
2·05	
2·07	
1·90	0·278 cc.
1·90	
1·80	
1·80	
s	
1·70	
1·90	
1·80	
1·95	
2·07	
2·15	
2·17	
2·17	
s′	
2·20	
2·27	
2·25	
2·40	
2·40	
2·30	
2·60	
lost.	
2·70	
2·80	
2·90	0·448 cc.
2·95	
3·15	
3·05	
2·30	
2·57	

NECROPSY.—Somewhat increased vascularity of mucous membrane of small intestine. Evidence of a very decided purgative effect: the contents of the small intestine being of a very watery character.

TABLE XXVI.—*Composition of the Bile before and after Sodium Phosphate.*

Experiment 51.	Before.	After.
Water,	84·69	85·15
Bile-acids, pigments, cholesterin, fats,	13·23	12·91
Mucus,	1·01	0·93
Ash,	1·07	1·01
	100·00	100·00
Velocity of secretion per half-hour,	3·6 cc.	5·5 cc.

Results of Experiments with Sodium Phosphate.—1. This substance is a powerful hepatic stimulant. 2. Although it renders the bile more watery, it increases the amount of biliary matter secreted per unit of time. 3. It is a moderately powerful intestinal stimulant, and, while acting as a purgative, it irritates the intestinal mucous membrane very slightly.

The results of Experiment 47 were so satisfactory—both doses of the substance producing an effect—that it was thought needless to repeat it, as it confirms Dr STEPHENSON's observations on the human subject, adding to these, however, the definite knowledge that it has the power of actually increasing the flow of the bile, and that it does so by stimulating the hepatic cells.

It will be shown by Experiment 65 that ammonium phosphate is also a powerful hepatic stimulant.

ACTION OF SODIUM SULPHATE.

Works on therapeutics generally make no mention of any cholagogue action of this substance. In the fourth edition of GARROD'S *Materia Medica,* however, it is stated that, in addition to its action as a saline purgative, it "probably influences the biliary secretion." 240 to 480 grains is the dose for a man.

Experiment 48. Dog that had fasted nineteen hours. Weight 19·5 kilogrammes (fig. 48).—12 cc. water injected into duodenum at *w*. 60 grains sodium sulphate in 12 cc. water injected at *s*, and again at *s'*.

NECROPSY.—Evidence of decided purgative action in small intestine, the mucous membrane of which exhibited a considerably increased vascularity.

Experiment 48A. Dog that had fasted twenty hours. Weight 15·7 kilogrammes (fig. 48A).—3 cc. bile and 5 cc. water—heated to 37° C.—injected into duodenum at *b*. 508 grains sodium sulphate, in the same fluid heated to 37° C., injected at *s*.

Experiment 48.		Experiment 48A.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·25		1·00	
0·25		0·95	
0·30		0·95	
0·40		0·95	
0·55	0·107 cc.	*b* ——	
0·50		0·95	0·251 cc.
0·50		1·05	
w ——		0·95	
0·55		1·00	
s ——		*s* ——	
0·80		1·00	
1·00	0·266 cc.	1·10	
1·05		1·05	
1·65		1·15	
1·50		1·25	
0·65		1·40	
1·00		1·45	
s′ ——		1·50	0·388 cc.
0·60		1·60	
1·30	0·279 cc.	1·55	
1·40		1·45	
1·50		1·55	
1·25		1·45	
		1·35	
		1·50	
		1·45	
		1·55	
		1·35	

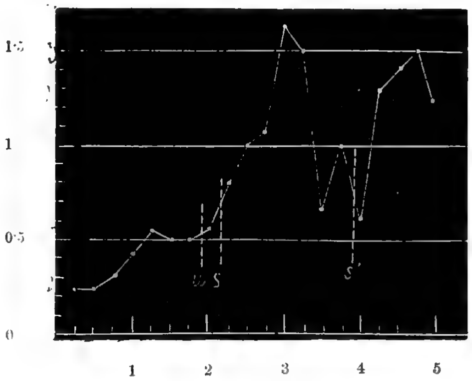

Fig. 48.—Secretion of bile before and after sodium sulphate. 12 cc. water injected into duodenum at *w*. 60 grains sodium sulphate in 12 cc. water injected at *s*, and again at *s′*.

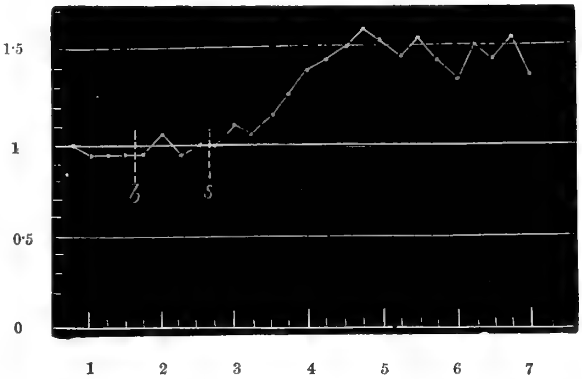

Fig. 48A.—Secretion of bile before and after sodium sulphate. 3 cc. bile and 5 cc. water, heated to 37° C., injected into duodenum at *b*. 508 grains sodium sulphate, in the same fluid heated to 37° C., injected at *s*.

Necropsy.—Mucous membrane of whole length of small intestine slightly reddened. The small intestine contained 147 cc. of clear fluid with greenish flakes, thus affording evidence of a decided purgative effect.

Table XXVII.

Sodium Sulphate.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 48, .	120	6·1	0·10 cc.	0·25 cc.
„ 48A, .	508	32·3	0·25 cc.	0·38 cc.

Results of Experiments with Sodium Sulphate.—In addition to being a powerful intestinal stimulant, it is also a moderately powerful hepatic stimulant. The positive character of this result is important, because it is well known that the waters of Carlsbad have a cholagogue action, and although they contain, in addition to sodium sulphate, sodium carbonate, sodium chloride, potassium sulphate, and small quantities of other substances, sodium sulphate is the principal salt, and to it the cholagogue action is doubtless chiefly due.

Sodium sulphate, however, has for a considerable time been, in practical medicine, almost entirely superseded by magnesium sulphate, on account of its more agreeable taste, but it must in future be borne in mind that while sodium sulphate stimulates the liver, magnesium sulphate does not. (*See* Experiments 18 and 19.)

Action of Potassium Sulphate.

Potassium sulphate is sometimes employed as a purgative agent, but no mention is made in the books of its having any action on the liver. Dr Wade of Birmingham, however, informed us that he finds this substance a cholagogue in man, and at his request we tested its action on the liver of the dog by our method.

Experiment 49. Dog that had fasted seventeen hours. Weight 17 kilogrammes (fig. 49).—$2\frac{1}{2}$ cc. bile and 16 cc. water injected into duodenum at *b*. The same with 124 grains potassium sulphate heated to 37° C. injected at *p*.

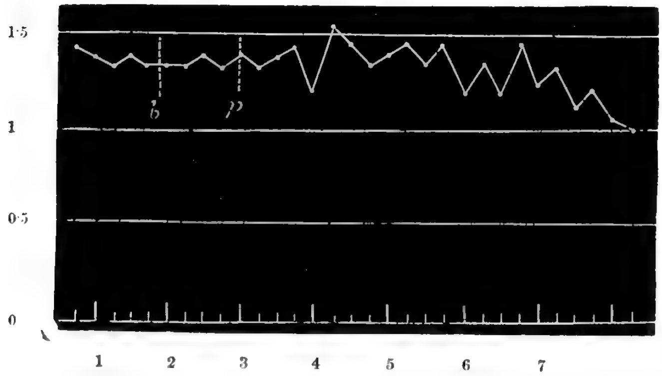

Fig. 49.—Secretion of bile before and after potassium sulphate. $2\frac{1}{2}$ cc. bile and 16 cc. water injected into duodenum at *b*. The same with 124 grains potassium sulphate, heated to 37° C., injected at *p*.

Experiment 49.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·45		1·42	
1·40		1·35	
1·35		1·40	
1·40		1·42	
1·32		1·35	
b ——		1·42	
1·32	0·315 cc.	1·20	
1·32		1·35	
1·40		1·20	
1·32		1·45	
p ——		1·27	
1·40		1·37	
1·32		1·17	0·266 cc.
1·40		1·22	
1·42		1·10	
1·20		1·02	
1·52			

Necropsy.—Small intestine contained 137 cc. greenish fluid with mucous flakes. The mucous membrane exhibited increased vascularity with small ecchymoses in its upper fourth.

In this case, therefore, this substance irritated the intestine and produced purgation, but did not excite the liver. It was decided to give in the next case a larger dose.

Experiment 49A. Large dog that had fasted seventeen hours. Weight not recorded (fig. 49A).—2½ cc. bile and 35 cc. water injected into duodenum at *b*, the same with 142 grains potassium sulphate injected at *s*, and again at *s′*.

	Experiment 49A.
	Secretion of bile per 15″.
	cc.
	2·20
	2·14
	2·20
	2·15
b	—
	2·20
	2·20
	2·15
	2·22
s	—
	2·20
	2·35
	2·37
	2·40
	2·30
	2·40
	2·25
	2·32
	2·20
	2·10
	1·95
s′	—
	1·90
	2·05
	2·20
	2·30
	2·20
	2·25
	2·05
	2·22
	2·05
	2·20
	1·95
	1·85
	1·95

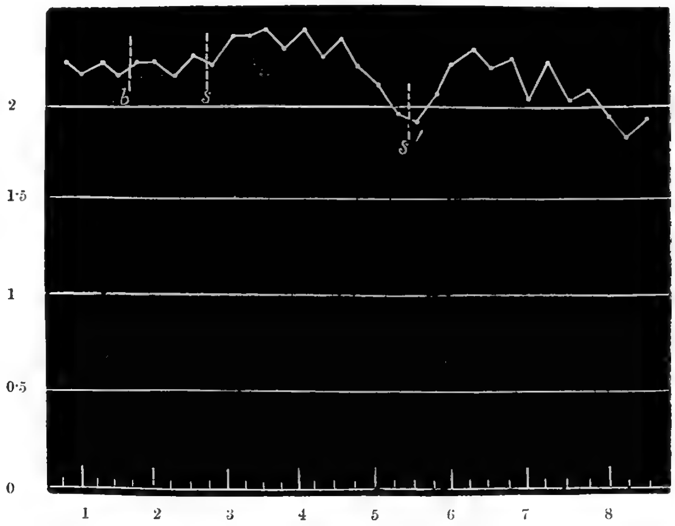

Fig. 49A.—Secretion of bile before and after potassium sulphate. 2½ cc. bile and 35 cc. water injected into duodenum at *b*, the same with 142 grains potassium sulphate injected at *s*, and again at *s′*.

NECROPSY.—Small intestine contained 143 cc. watery fluid. The vascularity of the mucous membrane in the whole length of the small intestine was slightly increased.

There being in this case evidence of a slight increase of the biliary secretion, another experiment was thought desirable.

Experiment 49B. Dog that had fasted seventeen hours. Weight 21·5 kilogrammes (fig. 49B).—232 grains potassium sulphate dissolved in 32 cc. water at 37° C. and injected into duodenum at *p*.

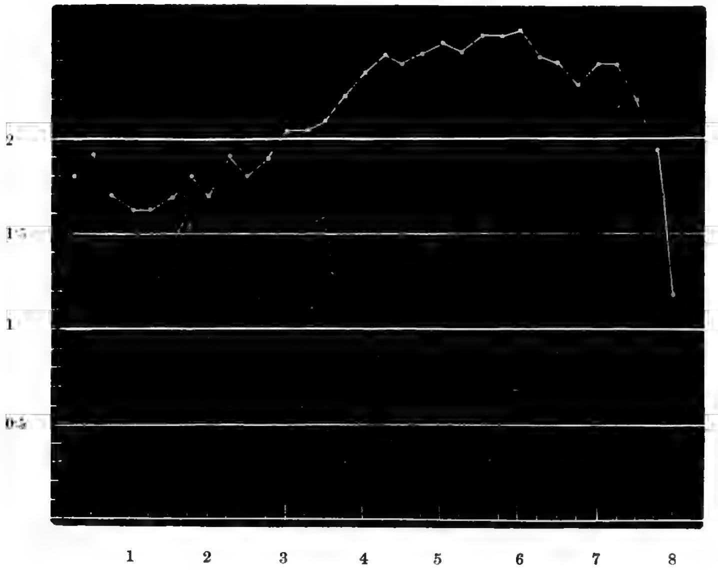

Fig. 49B.—Secretion of bile before and after 232 grains potassium sulphate dissolved in 32 cc. water at 37° C., and injected into duodenum at *p*.

Experiment 49B.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
1·80	
1·90	
1·70	0·316 cc.
1·65	
1·65	
1·70	
p ——	
1·80	
1·70	
1·90	
1·80	
1·90	
2·05	
2·07	
2·10	
2·25	
2·37	
2·45	
2·40	
2·45	
2·50	
2·47	
2·55	0·47 cc.
2·55	
2·57	
2·45	
2·40	
2·30	
2·40	
2·40	0·352 cc.
2·20	
1·95	
1·20	

NECROPSY.—Increased vascularity of mucous membrane in whole length of small intestine. The small intestine contained 90 cc. clear brownish fluid, with numerous mucous flakes. There was, therefore, evidence of considerable purgative action.

Results of Experiments with Potassium Sulphate.—Experiment 49B shows that potassium sulphate is undoubtedly a hepatic stimulant. The dose of 232 grains, given in this case to a full-sized dog, was just the maximum dose for a man. The negative effect of 124 grains in Experiment 49, and the slight effect of 142 grains twice repeated in Experiment 49A, show that this substance is uncertain in its action on the liver. Regarding its action on the intestinal glands, however, there was no uncertainty, for its purgative effect was pronounced in all the three experiments. Possibly, the sparing solubility of the salt may render its absorption into the portal vein uncertain. The bile given along with the salt in Experiments 49 and 49A had probably nothing whatever to do with the result. The result of Experiment 49B completely supports Dr Wade's opinion, that potassium sulphate is a cholagogue. Indeed, the amount of bile secreted per kilogramme of body-weight under its influence in that experiment was greater than in either of the experiments with sodium sulphate (48 and 48A). The apparent uncertainty, however, in the action of potassium sulphate must not be lost sight of.

Action of Sodium Bicarbonate.

The previously mentioned salts of sodium and potassium having all been found to have some action on the liver, it was determined to try the effect of the bicarbonates.

Experiment 50. Dog that had fasted eighteen hours. Weight 16·3 kilogrammes (fig. 50).—5 cc. water and 2 cc. bile were injected into the duodenum at *b* (a needless precaution); 31 grains of sodium bicarbonate in the same fluid were injected at *s*, *s′*, and *s″*; and 124 grains in 15 cc. water and 2 cc. bile were injected at *s‴*: 217 grains being given in all. Only after the last dose did the secretion of bile begin to rise slightly.

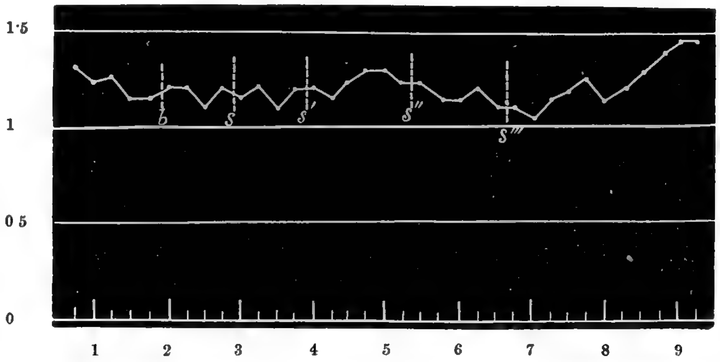

Fig. 50.—Secretion of bile before and after sodium bicarbonate. 5 cc. water and 2 cc. bile injected into the duodenum at *b*. The same with 31 grains sodium bicarbonate injected at *s*, *s′* and *s″*. 15 cc. water with 2 cc. bile and 124 grains sodium bicarbonate injected at *s‴*.

Necropsy.—The vascularity of the mucous membrane of the small intestine was slightly increased. The viscus contained 60 cc. of a greenish mucous fluid.

Experiment 50A.—Dog that had fasted eighteen hours. Weight 19·9 kilogrammes (fig. 50A).—5 cc. of water and 2·5 cc. of bile were injected into the duodenum at *b* (a needless precaution), and the same fluid, with 64 grains of sodium bicarbonate, was injected at *s*, *s′*, and *s″*—192 grains being given in all. The secretion of bile rose slightly after each dose.

Result of Experiments with Sodium Bicarbonate.—In Experiment 50, the hourly coefficient of secretion per kilogramme of body-weight during the first hour was 0·294 cc.; during the seventh hour, it was 0·287 cc.; and during the last hour, after 217 grains of the salt had been given, it was 0·341 cc. In Experiment 50A the coefficient during the first hour was 0·23 cc.; during the fifth hour, when the secretion was at its height, it rose to 0·28 cc.,—128 grains of sodium bicarbonate having been given. It is, therefore, evident that, though the blood of the portal vein was, comparatively speaking, laden with this very readily decomposable sodium salt, the hepatic cells were scarcely at all excited thereby. It may, therefore, be inferred that, although sodium is required to form the salts of the bile-acids, a liberal supply of sodium has a feeble influence in leading to an increased formation of bile. Sodium bicarbonate is, therefore, an exceedingly feeble hepatic excitant even in large doses; and it may, therefore, be inferred that the ordinary dose of 10 or 20 grains, given to the human subject, produces no appreciable influence on his bile-secretion. It should be stated that the introduction of bile into the intestine—though of great service when resinous substances are given, as has been already explained—was in these experiments entirely needless. Indeed, the introduction of 10 cc. of bile in the case of dog 50 was of itself calculated to slightly increase the bile-secretion; but in Experiment 50A the distinct rise of secretion after each dose of the sodium salt was combined with the 2 cc. of bile and water that had previously had no effect, clearly shows that the sodium bicarbonate was the cause of the increased hepatic activity.

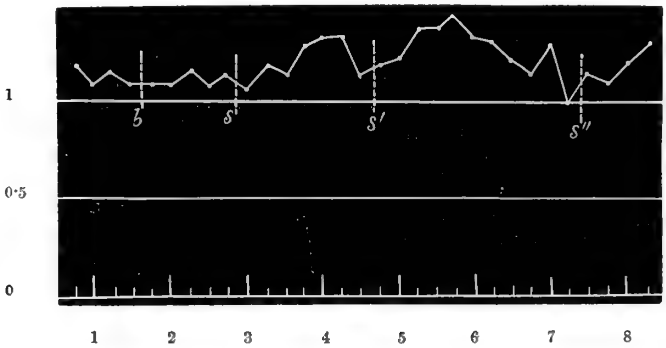

Fig. 50A.—Secretion of bile before and after sodium bicarbonate. 5 cc. water and 2·5 cc. bile injected into duodenum at *b*. The same with 64 grains sodium bicarbonate injected at *s*, *s'*, and *s''*.

Action of Potassium Bicarbonate.

Experiment 51. Dog that had fasted eighteen hours. Weight 19·3 kilogrammes (fig. 51).—31 grains of potassium bicarbonate in 8 cc. of water were injected into the duodenum at p, p', and p'', and 108 grains in 8 cc. of water were injected at p'''—201 grains being given in all. The bile-secretion was distinctly increased.

Necropsy.—53 cc. of a clear brownish fluid, with numerous mucous flakes in small intestine. Vascularity of mucous membrane considerably increased.

Result of Experiment with Potassium Bicarbonate.—Before the alkaline salt was given, the hourly coefficient of secretion per kilogramme of body-weight was 0·238 cc.; and, after 201 grains had been given, it rose to 0·384 cc. Seeing that 31 grains produced no effect, it may be safely assumed that, when a dose of 10 or 15 grains is taken by man, his biliary secretion is not sensibly affected.

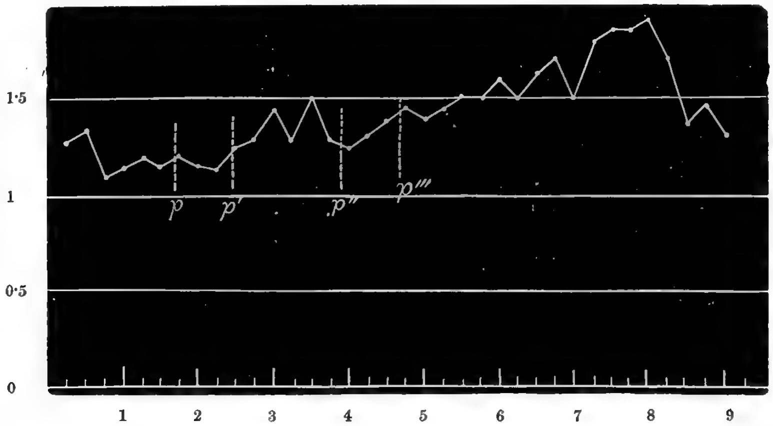

Fig. 51.—Secretion of bile before and after potassium bicarbonate. 31 grains in 8 cc. water injected into duodenum at p, p', and p''. 108 grains in 8 cc. water injected at p'''.

Experiment 51.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·30		1·40	
1·35		p''' ——	
1·10	0·238 cc.	1·45	
1·15		1·40	
1·20		1·45	
1·15		1·50	
p ——		1·50	
1·20		1·60	
1·15		1·50	
1·15		1·67	
p' ——		1·70	
1·25		1·50	
1·30		1·80	0·384 cc.
1·45	0·287 cc.	1·85	
1·30		1·85	
1·50		1·90	
1·30		1·70	
p'' ——		1·40	
1·25		1·45	
1·30		1·30	

ACTION OF IODIDE OF POTASSIUM.

Potassium iodide is sometimes administered in hepatic affections, in the hope that it may produce an "alterative" effect. On that account it seemed desirable to ascertain whether or not it affects the biliary secretion.

Experiment 52. Dog that had fasted eighteen hours. Weight 17 kilogrammes (fig. 52).—10 grains of potassium iodide in 3 cc. of water were injected into the duodenum at p, 20 grains at p', and 30 grains at p''. There was no increase of secretion, but, on the contrary, a rather greater fall than is usually observed in a normal case. A repetition of the experiment was therefore necessary.

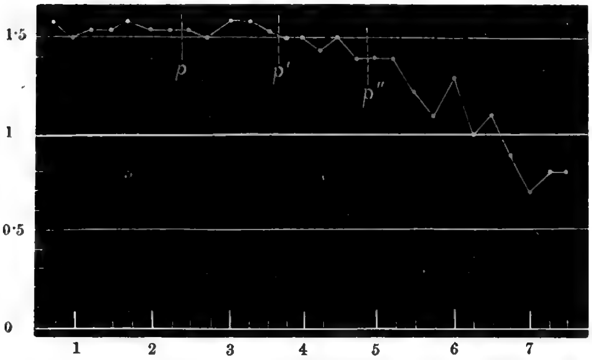

Fig. 52.—Secretion of bile before and after potassium iodide. At p 10 grains, at p' 20 grains, and at p'' 30 grains in 3 cc. of water injected into the duodenum.

Necropsy.—54 cc. of a thick yellowish mucous fluid found in the small intestine, thus affording evidence of a slight purgative action.

Experiment 52a. Dog that had fasted nineteen hours. Weight 16·9 kilogrammes (fig 52a).—5 grains of potassium iodide in 2 cc. of water were injected into the duodenum at p, 10 grains in 2 cc. of water at p', 20 grains in 5 cc. of water at p'', 30 grains in 5 cc. of water at p''', and 40 grains in 8 cc. of water at p''''. The trifling increase of secretion after the second and fourth doses may be discarded, and the fall of secretion as the experiment advanced might very probably have been equally marked had nothing been given.

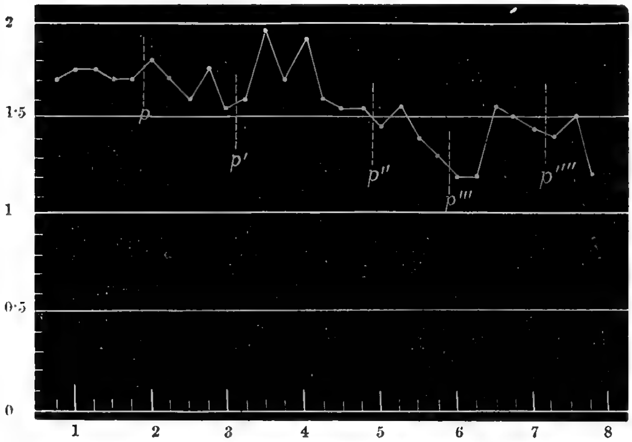

Fig. 52a.—Secretion of bile before and after potassium iodide. At p 5 grains in 2 cc. of water, at p' 10 grains in 2 cc. of water, at p'' 20 grains in 5 cc. of water, at p''' 30 grains in 5 cc. of water, and at p'''' 40 grains in 8 cc. of water, injected into the duodenum.

Necropsy.—Small intestine contained 25 cc. of a clear mucous fluid, indicating a slight purgation; for, though 22 cc. of water had been injected, much of it had doubtless been absorbed.

Result of Experiments with Potassium Iodide.—This substance does not appear to affect the biliary secretion.

Action of Physostigma.

Since the well-known researches of Sir Robert Christison and Professor Fraser, the physiological actions of Calabar bean have been made the subject of extensive inquiry; its action on the liver has not, however, hitherto been investigated, owing to the want of a reliable method of experiment. As stated by Professor **Fraser**, this agent excites the salivary, intestinal, and lachrymal glands; and at his request we performed the following experiments on the liver. The extract of Calabar bean of the "British Pharmacopœia" was the preparation employed, the maximum dose of which for the human subject is a quarter of a grain.

Experiment 53. Dog that had fasted eighteen hours. Weight 26·7 kilogrammes (fig. 53).—1 grain extract of Calabar bean triturated with half cc. of bile, half cc. of rectified spirit, and 5 cc. of water, was injected into the duodenum at *c*, and the same dose was given again at *c′*. The increased secretion of bile was decided and prolonged after the second dose. The bile and alcohol were employed merely to promote absorption of the active principle, and it may be safely assumed that none of the effect was directly due to either, for it has been already stated that 2 cc. or 3 cc. of bile introduced into the duodenum does not notably affect the biliary secretion; and it will be shown that a much larger quantity of alcohol than was given in this case has also no effect (Experiments 73 and 74).

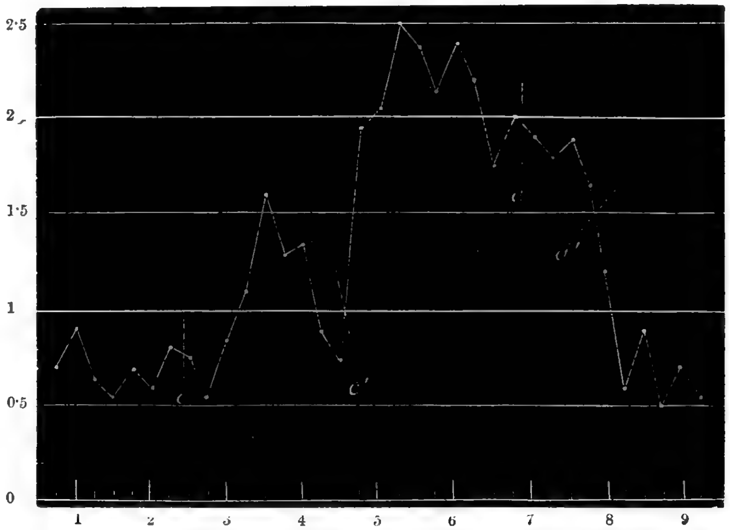

Fig. 53.—Secretion of bile before and after Calabar bean and atropia. 1 grain extract Calabar bean with ½ cc. bile, ½ cc. rectified spirit, and 5 cc. water, injected into duodenum at *c*, and again at *c′*; ⅙ths grain atropia sulphate injected into duodenum at *a*; ⅙ths grain into jugular vein at *a′*.

Experiment 53.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·70		2·50	
0·90		2·40	0·365 cc.
0·65		2·15	
0·55	0·098 cc.	2·40	
0·70		2·20	
0·60		1·75	
0·80		2·00	
c ——		*a* ——	
0·75		1·90	
0·55		1·80	
0·85		1·90	
1·10		1·65	
1·60		*a′* ——	
1·30		1·20	
1·35		0·60	
0·90		0·90	0·098 cc.
0·75		0·50	
c′ ——		0·70	
1·95		0·55	
2·05			

Although the antagonism between atropia and physostigma has been abundantly proved by **Fraser**, **Arnstein**, **Heiden**-

HAIN, and others, it was nevertheless deemed desirable to definitely ascertain whether or not, in the case of the liver, this antagonism also obtains; accordingly, four-fifths of a grain of atropia sulphate, dissolved in 3 cc. of water, was injected into the duodenum at *a*. The effect being somewhat doubtful, three-fifths of a grain dissolved in 3 cc. of water was injected into the jugular vein. The bile-secretion speedily fell, and it is evident from the chart that within half-an-hour after the administration of the second dose the effect of the physostigma had entirely disappeared.

NECROPSY.—There was decided irritation of the duodenal mucous membrane to the extent of 8 inches below the pylorus. Evidence of only slight purgative action was found in the small intestine.

Experiment 53A. Dog that had fasted eighteen hours. Weight 13·6 kilogrammes (fig. 53A).—Two grains of the extract of Calabar bean, triturated with 1 cc. bile and 5 cc. water, were injected into the duodenum at *c*. The

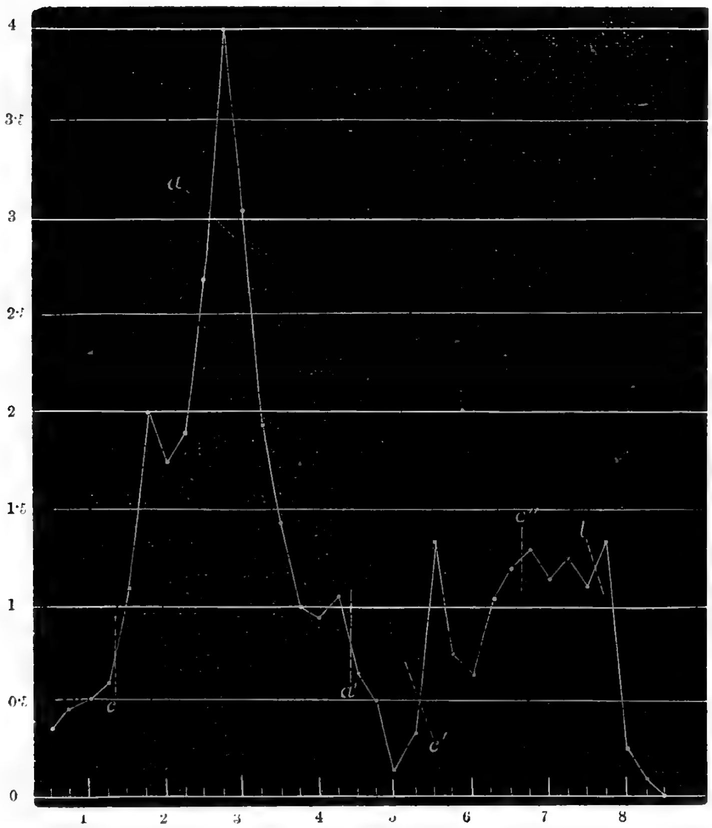

Fig. 53A.—Secretion of bile before and after Calabar bean, atropia, and lead acetate. 2 grains extract of Calabar bean with 1 cc. of bile and 5 cc. of water injected into the duodenum at *c*; 1½ grain extract, with same, at *c'*; 2 grains extract, with same, at *c''*; ⅘ths of a grain of atropia sulphate in 4 cc. of water injected into the jugular vein at *a*; ⅗ths of a grain at *a'*; 8 grains of lead acetate in 20 cc. of water injected into the duodenum at *l*.

Experiment 53A.

	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
	cc.	
	0·35	0·138 cc.
	0·45	
	0·50	
	0·60	
c		
	1·10	
	2·00	
	1·75	0·753 cc.
	1·90	
	2·70	
a		
	4·00	
	3·05	
	1·95	
	1·45	
	1·00	
	0·95	
	1·05	
a'		
	0·65	0·121 cc.
	0·50	
	0·15	
	0·35	
c'		
	1·35	
	0·85	
	0·75	
	1·05	
	1·10	
c''		
	1·30	
	1·15	
	1·25	
	1·10	
l		
	1·35	
	0·25	
	0·00	

stimulating effect on the liver was rapid and very powerful. Four-fifths of a grain of atropia sulphate, dissolved in 4 cc. water, was injected into the jugular vein at *a*. This was done just five minutes before the next reading of the bile. It is, therefore, certain that much of the bile that formed the highest reading in the experiment was secreted previous to the injection of the atropia; and, as atropia did not increase the secretion in the preceding experiment, it follows that the very high reading of the bile immediately subsequent to the atropia administration is to be attributed to the action of the physostigma not yet antagonised. Ere long, however, the atropia asserted its influence and antagonised the physostigma. At *a′*, three-fifths of a grain of atropia sulphate was again injected into the jugular vein, and it is evident from the chart that the physostigma was completely antagonised thereby. A continuation of the experiment was, perhaps, scarcely necessary; still a grain and a half of Calabar extract, triturated with 1 cc. bile and 5 cc. water, was injected into the duodenum at *c′*, and two grains of the extract similarly treated were injected at *c″*. The exciting effect was not very marked; nor need this be wondered at, considering how powerfully the liver had been previously stimulated, and its partial exhaustion induced not merely owing to the above cause, but also owing to the duration of the experiment.

As the action of acetate of lead on the liver was to be investigated, eight grains of that substance, dissolved in 20 cc. of water, were injected into the duodenum at *l*, and the secretion of bile soon thereafter came to a standstill. Subsequent experiments show that this effect was unusual and attributable to the depressant effect of the lead on a liver already well-nigh exhausted.

NECROPSY.—Great irritation of the mucous membrane of the small intestine to the extent of about fifteen inches below the pylorus. The viscus contained only slight evidence of purgative action.

Result of Experiment with Physostigma.—The relation of the dose to the size of the animal, and the coefficients of the secretion before and after its administration, are stated in Table XXVIII.

TABLE XXVIII.

Physostigma.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 53, .	2 with bile	0·0074	0·098 cc.	0·365 cc.
Experiment 53A, .	2 ,,	0·0147	0·138 cc.	0·753 cc.

It is interesting to observe that in Experiment 53A the dose, which, in relation to the size of the animal, was twice as great as in Experiment 53, raised the coefficient of secretion to a little more than twice the figure attained in Experiment 53, showing forcibly the precision of the experimental method employed. The high coefficient in Experiment 53A indicates a very powerful effect; yet, since the dose employed was four times the maximum dose for a man, and seeing that one grain produced only a trifling effect in Experiment 53, it may be inferred that, in the human subject, physostigma will probably be found to have, in the relatively small doses administered, an insignificant effect on the liver; for many of the preceding experiments have demonstrated that, when the same dose of a substance that powerfully excites the human liver is given to an average-sized dog, it powerfully excites its liver. It is an error to suppose that the dog requires much larger doses of all drugs than are necessary for the human subject. The effect of physostigma on the liver is completely antagonised by atropia sulphate.

Prevost of Geneva, in a communication to the Paris Academy of Sciences (August 3, 1874), states that muscaria increases the biliary secretion, and that atropia checks the hypersecretion due to muscaria.

Action of Atropia.

It is known that atropia causes purgation and diuresis in dogs (*Op.* viii. p. 322). On the other hand, it paralyses the chorda tympani and the secretory nerves of the sweat and milk glands, and thereby arrests their secretions. It therefore seemed desirable to give atropia previous to the administration of any other substance, in order to determine its influence on the liver.

Experiment 54. Dog that had fasted eighteen hours. Weight 16·1 kilogrammes (fig. 54.)—In this experiment the secretion of bile rose at the end of the first hour, although no drug had been administered. Our previous experiments have convinced us that this is due to reaction, which is apt to ensue unless great care is taken to pull as little as possible at the bile-duct during the operation for inserting the cannula.

Half a grain of atropia sulphate, dissolved in twenty minims of water, was injected into the jugular vein at a, a', a'', and again at a'''; and one grain was injected at a''''. Thus three grains were given in all. The fall of secretion after the first dose may be discarded, as it would probably have taken place had no atropia been given. It is evident that the atropia does not arrest the secretion of bile as it does that of saliva, sweat, and milk. Nor can it be said to augment it; for the increased secretion that followed the third dose is trivial, and may be discarded in view of the sequel to the second dose in Experiment 53A.

Ten grains of acetate of lead, dissolved in 20 cc. of tepid water, were injected into the duodenum at *l*, without producing any notable effect.

Having, in other experiments—mentioned in the sequel—discovered that the alkaline salts of benzoic acid are powerful hepatic stimulants, we suspected that the alkaline salts of salicylic acid would be found to have a similar action. Accordingly, twenty-five grains of sodium salicylate, dissolved in 25 cc. of water, were injected into the duodenum, and within half an hour a very rapid secretion of bile had begun; and this, notwithstanding the previous administration of lead acetate and three grains of atropia sulphate.

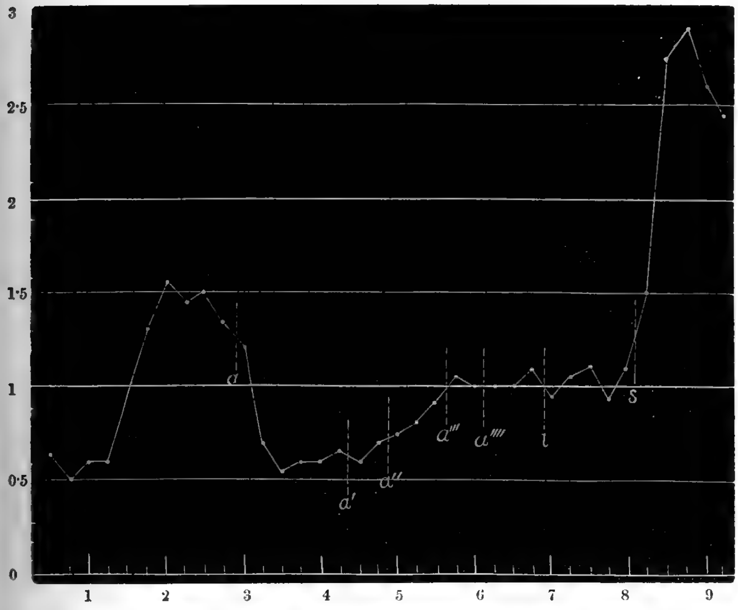

Fig. 54.—Secretion of bile before and after atropia sulphate, lead acetate, and sodium salicylate. ½ grain of atropia sulphate in 20 minims of water injected into jugular vein *a*, *a'*, *a''*, and *a'''*; 1 grain injected into vein at *a''''*; 10 grains of lead acetate in 20 cc. of warm water injected into the duodenum at *l*; 25 grains of sodium salicylate in 25 cc. of water injected into the duodenum at *s*.

Experiment 54.		
	Secretion of bile per 15.″	Secretion of bile per kilogramme of dog: per hour.
	cc.	
	0·65	
	0·50	
	0·60	
	0·60	
	1·00	
	1·30	
	1·55	
	1·45	
	1·50	
	1·35	
a	——	
	1·20	
	0·70	
	0·55	
	0·60	
	0·60	
	0·65	
a'	——	
	0·60	
	0·70	
a''	——	
	0·75	
	0·80	
	0·90	
a'''	——	
	1·05	
	1·00	
a''''	——	
	1·00	
	1·00	
	1·10	
l	——	
	0·95	0·260 cc.
	1·05	
	1·10	
	0·95	
	1·10	
s	——	
	1·50	0·664 cc.
	2·75	
	2·90	
	2·60	
	2·45	

Result of Experiments with Atropia.—Atropia sulphate does not paralyse the hepatic cells, neither does it appear to excite them. Whether or not it possesses the power of paralysing the hepatic secretory nerves is doubtful; but, seeing that it antagonises the effect of physostigma on the liver, and remembering the action of these substances on the nerves of the heart and salivary glands, the suspicion is entertainable that physostigma stimulates the hepatic cells through a nervous apparatus that is affected in an opposite sense—possibly paralysed—by atropia; while the hepatic cells, and perhaps some nervous mechanism like the motor ganglia of the heart in close relation to them, are unaffected by atropia.

Action of Resina Menispermi or "Menispermin."

The substance termed menispermin by Keith & Co. of 41 Liberty Street, New York, is derived from the root of the yellow parilla (*Menispermum canadense*). Messrs Keith have informed me that the crude root of the plant is dried, crushed, and percolated with alcohol. The alcohol is then evaporated or distilled off, leaving the active principles in the form of an extract, which is then "freed from impurities," dried, and pulverised. How it is *freed from impurities* is not stated. This is also the manner in which they prepare baptisin, phytolaccin, hydrastin, and juglandin—substances whose actions are described in the sequel.

Menispermin is stated by Keith (*Op.* xiv.) to be "alterative, tonic, laxative, diuretic, stimulant, and resolvent, and to be useful in hepatic torpor, indigestion," &c. On this account, we experimented with it on the liver; but we probably would not have taken the trouble had we at the time been aware of the account given of its effects by Wood and Bache (*Op.* x. p. 1555). In that account the root is said to be a gently stimulating tonic, probably very closely allied to calumba, which also belongs to the Menispermaceæ. The medium dose of Keith's menispermin for a man is two grains.

Experiment 55. Dog that had fasted eighteen hours. Weight 23·1 kilogrammes (fig. 55).—Seven grains of menispermin, triturated with 1·5 cc. of bile and 3 cc. of water, were injected into the duodenum at *m*; and, as no obvious effect ensued, seven grains of baptisin, similarly treated, were injected into the duodenum at *b*. The secretion of bile thereafter speedily rose. The result was evidently somewhat equivocal, and therefore another experiment, in which menispermin was alone given, was performed.

Necropsy.—The duodenal mucous membrane showed only one slightly reddened patch. There was but scanty evidence of purgative action, for the upper part of the small intestine contained only 35 cc. of fluid; but whether due to a purgative action of the menispermin, or of the baptisin, could not be apparent from this experiment.

Experiment 56. Dog that had fasted seventeen hours. Weight 15·7 kilogrammes (fig. 56).—Two cc. of bile and 2 cc. of water were injected into the duodenum at *b*. This producing no perceptible effect on the secretion, five grains of menispermin were triturated with the same amount of bile and water, and injected into the duodenum at *m*; and the same dose was repeated at *m′*. The secretion remaining unaffected, ten grains with bile and water, as before, were injected at *m″*. The bile-secretion was remarkably constant, and the experiment clearly proved that this substance, even in large doses, does not excite the liver; and that the rise of secretion observed in Experiment 55

Experiment 55.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1.65		1·40	0·233 cc.
2·00	0·311 cc.	1·35	
1·95		1·35	
1·80		*b* ——	
1·55		1·50	
m ——		1·65	
1·45		1·95	0·394 cc.
1·40		2·10	
1·30		3·00	
1·25		2·05	
1·05		1·95	
1·30	0·233 cc.	1·75	

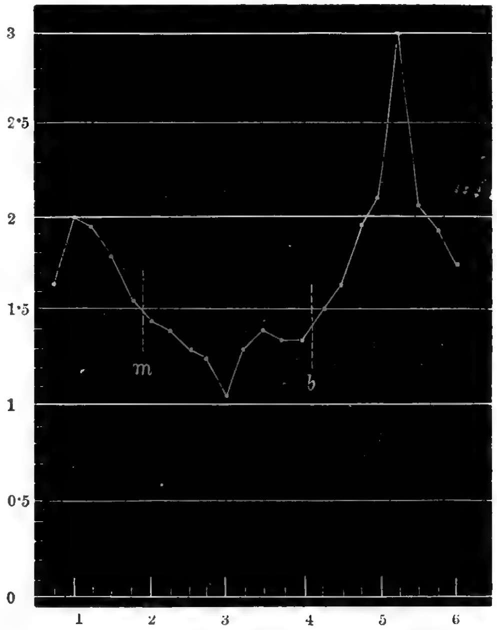

Fig. 55. Secretion of bile before and after menispermin and baptisin. 7 grains of menispermin in 1·5 cc. of bile and 3 cc. of water injected into the duodenum at *m*; 7 grains of baptisin in 2 cc. of bile and 3 cc. of water injected at *b*.

Experiment 56.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·4		*m′* ——	
1·4		1·30	
1·3		1·25	
1·4	0·34 cc.	1·15	0·315 cc.
b ——		1·25	
1·4		1·30	
1·3		1·25	
1·25		*m″* ——	
m ——		1·30	
1·25		1·15	
1·20		1·16	0·287 cc.
1·25		1·25	
1·30		1·05	
1·15		1·05	

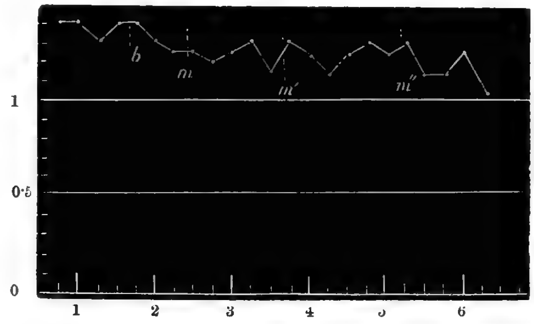

Fig. 56. Secretion of bile before and after menispermin. 2 cc. of bile and water injected into the duodenum at *b*; the same, with 5 grains of menispermin, injected at *m*, and again at *m′*; the same, with 10 grains injected at *m″*.

could not be ascribed to the menispermin. Indeed, the chart of this experiment (fig. 56) simply shows the normal curve of bile-secretion in a fasting animal.

Necropsy.—The mucous membrane of the upper third of the small intestine was slightly reddened, and there was evidence of decided purgative action; for, while only 16 cc. of fluid had been injected, the small intestine contained 170 cc. of yellowish fluid containing much mucus.

Result of Experiments with Menispermin.—This substance is an intestinal, but not a hepatic, stimulant.

Action of Resina Baptisiæ or "Baptisin."

The substance termed "baptisin" is an impure resin prepared from the root of the wild indigo plant (*Baptisia tinctoria*) after the same manner as menispermin. The specimen employed in these experiments was obtained from Keith & Co. of New York. The root of this plant is said to be a powerful emetic and cathartic in large, and a mild laxative in small, doses. Stevens of Pennsylvania recommends a decoction of the root in epidemic dysentery. It is said to have proved useful in scarlatina, typhus fever, and in that state of the system that attends mortification (*Op.* x. p. 1469). The physiological actions of this plant have apparently not been investigated, and it is nowhere stated that it is a cholagogue. The dose of baptisin for a man is from one to five grains.

In Experiment 55 it has already been shown that baptisin increases the biliary secretion; but, as in that experiment its administration followed that of menispermin, it was desirable to give baptisin first in another experiment.

Experiment 57. Dog that had fasted seventeen hours. Weight 18·7 kilogrammes (fig. 57.)—Seven grains of baptisin triturated with 2 cc. of bile and 5 cc. of water were injected into the duodenum at *b*. In half an hour its

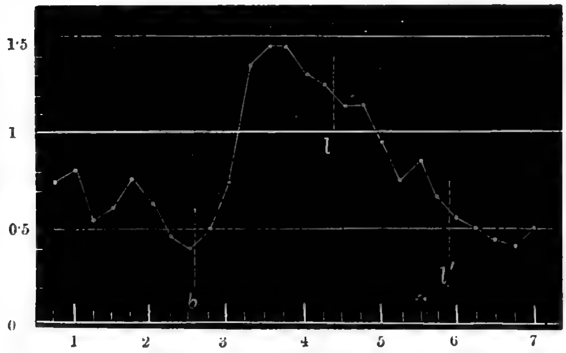

Fig. 57. Secretion of bile before and after baptisin and lead acetate. 7 grains of baptisin, with 2 cc. of bile and 5 cc. of water, injected into the duodenum at *b*; 8 grains of lead acetate in 15 cc. of water injected at *l*; 12 grains in 25 cc. of warm water at *l′*.

Experiment 57.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·75		1·30	0·296 cc.
0·80		1·25	
0·55		*l* ——	
0·60		1·15	
0·75	0·120 cc.	1·15	
0·65		0·95	
0·45		0·75	
0·40		0·85	
b ——		0·65	
0·45		*l′* ——	
0·50		0·55	
0·75		0·50	0·098 cc.
1·35	0·296 cc.	0·45	
1·45		0·40	
1·45		0·50	

stimulating effect on the liver was perceptible, and in the course of an hour it became very evident. As this result confirmed the observation made in Experiment 55, no more baptisin was given.

With a view to follow up the observations made with lead acetate in Experiments 53A and 54, eight grains of lead acetate dissolved in 15 cc. of water were injected into the duodenum at *l*, and twelve grains of the same in 25 cc. of tepid water were injected at *l′* into the lower part of the small intestine. The result was equivocal, in so far as the secretion of bile would doubtless have diminished had no lead been given. The experiment is, therefore, decisive as regards the action of baptisin, but inconclusive as regards that of lead.

NECROPSY.—Considerable redness of the mucous membrane of about 15 inches of upper part of small intestine. Slight evidence of purgative action.

Result of Experiments with Baptisin.—The two experiments with this substance prove it to be a hepatic stimulant, and Table XXIX. indicates its power as such.

TABLE XXIX.

Baptisin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 55, .	7 with bile,	0·303	0·233 cc.	0·394 cc.
„ 57, .	7 „	0·374	0·120 cc.	0·296 cc.

Taking into account the fact that in Experiment 57 the coefficient of bile-secretion did not rise higher than 0·296 cc., when nothing but baptisin had been administered, and at the same time the dose being relatively larger than in Experiment 55, it may be concluded that this substance is a hepatic and also an intestinal stimulant of moderate power, and it may possibly be found of service as a hepatic stimulant in cases of torpid liver with a depressed condition of the system tending to gangrene. We commend it to the attention of the physician.

ACTION OF RESINA PHYTOLACCÆ OR "PHYTOLACCIN."

The poke-plant (*Phytolacca decandra*) grows abundantly in the United States. The root is the part employed; and in small doses it is said to act as an alterative, and has been highly recommended in chronic rheumatism. In large doses it produces excessive vomiting and purging, with great prostration of strength, and sometimes with convulsions (*Op.* x. p. 646). The preparation employed by us was a substance termed "phytolaccin," prepared from the root of the plant by KEITH & Co. of New York, after the same manner as menispermin (page 210). The dose for a man is from one to three grains. The physiological actions of phytolacca have not hitherto been investigated.

Experiment 58. Dog that had fasted eighteen hours. Weight 31·1 kilogrammes (fig. 58.)—Two grains of phytolaccin triturated with 2 cc. of bile and 4 cc. of water were injected into the duodenum at *p*. The subsequent excitement of the liver was unequivocal. When the increase of secretion was well declared, one-tenth of a grain of atropia sulphate dissolved in ten minims of water was injected into the jugular vein at *a*, and again at *a′*, *a″*, *a‴*—in all four-tenths of a grain; but the stimulating effect of the phytolaccin was not antagonised thereby. Had this experiment been performed after instead of before Experiment 53, a larger dose of atropia would have been given. Remembering the non-exciting effect of atropia on the liver, the high secretion at the close of the experiment may be safely referred to the continued action of the phytolaccin.

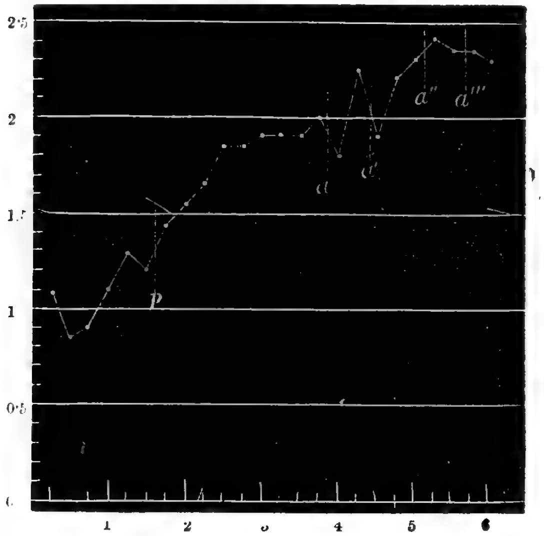

Fig. 58.—Secretion of bile before and after phytolaccin and atropia. 2 grains of phytolaccin in 2 cc. of bile and 4 cc. of water injected into the duodenum at *p*; 1-10th of a grain of atropia sulphate injected into the jugular vein at *a*, *a′*, *a″*, and *a‴*.

Experiment 58.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·10		2·00	0·244 cc.
0·85		*a* ——	
0·90		1·80	
1·10	0·144 cc.	2·25	
1·30		*a′* ——	
1·20		1·90	
p ——		2·20	
1·45		2·30	
1·55		*a″* ——	
1·65		2·40	
1·85		2·35	0·299 cc.
1·85		*a‴* ——	
1·90		2·35	
1·90	0·244 cc.	2·30	
1·90			

NECROPSY.—The duodenal mucous membrane was slightly reddened, but there was no evidence of purgative action worthy of mention.

Experiment 59. Dog that had fasted seventeen hours. Weight 19·2 kilogrammes (fig. 59).—Two cc. of bile and 2 cc. of water were injected into the duodenum at *b*, and 2 grains of phytolaccin triturated with the same fluids were injected at *p*. A considerable increase of bile-secretion ensued. Owing to the high secretion previous to the administration of the drug, the result is less striking than in the preceding experiment; yet, in this case, the coefficient of secretion was much higher than in the former experiment (Table XXX), a circumstance which was probably largely due to the fact that, while the same dose was given in both cases, the subject of Experiment 59 was much smaller than that of Experiment 58. The liver of the fifty-ninth dog was, therefore, more powerfully affected than that of the fifty-eighth dog.

Experiment 59.		
	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
	cc.	
	1·65	
	1·60	
	1·60	0·338 cc.
	1·65	
b	——	
	1·60	
	1·65	
p	——	
	1·55	
	1·75	
	1·90	
	1·80	
	1·80	
	2·15	
	2·30	
	2·20	
	2·15	
	2·25	
	2·15	
	2·30	0·471 cc.
	2·20	
	2·25	
	2·30	
	2·15	
	2·10	
	1·60	
	1·95	

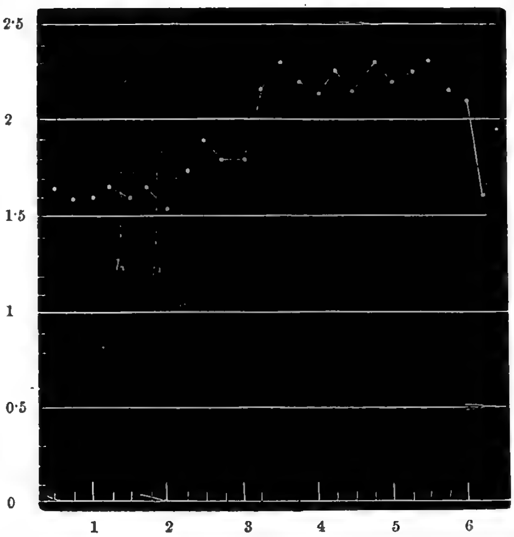

Fig. 59.—Secretion of bile before and after phytolaccin. 2 cc. of bile and 2 cc. of water injected into the duodenum at *b*; 2 grains of phytolaccin with 2 cc. of bile and 2 cc. of water injected at *p*.

NECROPSY.—The small intestine contained 40 cc. of liquid, indicating a mild purgative effect.

Result of Experiments with Phytolaccin.—It is a mild intestinal, but a powerful hepatic stimulant, as is shown by Table XXX.

TABLE XXX.

Phytolaccin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 58, .	2 with bile,	0·064	0·144 cc.	0·299 cc.
„ 59, .	2 „	0·104	0·338 cc.	0·471 cc.

Considering the small dose that was given, the high coefficient of secretion in Experiment 59 is probably to be regarded as a nearer indication than that in Experiment 58 of the power of phytolaccin as a hepatic stimulant. This substance appears to be eminently worthy of the attention of the physician.

ACTION OF RESINA HYDRASTIS OR "HYDRASTIN."

The root of the *Hydrastis canadensis* has had various medicinal properties claimed for it. It is admitted by all to be tonic, and by some it is said to be aperient, cholagogue, diuretic, antiseptic, &c. "It has been employed in dyspepsia, and other affections requiring tonic treatment, in jaundice and other functional disorders of the liver, as a laxative in constipation and hæmorrhoids, and as an alterative in various diseases of the mucous membranes, such as catarrh, chronic enteritis, &c. By some it is used as one of the best substitutes for quinia in intermittents." These and other statements regarding it are made by WOOD and BACHE (*Op.* x. p. 458), who further aver that a "more precise investigation of its physiological and therapeutic properties is necessary before we can venture to decide its place among medicines." It contains an alkaloid, hydrastia or hydrastin, which has been found to be identical with berberina (*Op.* x. p. 457), found in the *Berberis vulgaris* and in calumba. The "hydrastin" employed in the following experiments was not the alkaloid, but a resinous substance prepared from the root of the plant, in the same manner as menispermin (p. 210) by KEITH & Co. of New York. The dose for a man of this preparation is from one to two grains.

Experiment 60. Dog that had fasted seventeen hours. Weight 25·9 kilogrammes (fig. 60).—Two grains of hydrastin triturated with 2 cc. of rectified spirit, 1 cc. of bile, and 2 cc. of water were injected into the duodenum at *h*, and the same dose was repeated at *h'*. A wave, as it were, of increased bile-secretion followed both doses, the second being higher than the first. It is notable that the periods of excitement after both doses were of the same length—an hour and a half. Twenty grains of sodium salicylate in 10 cc. of water were then injected into a lower part of the small intestine (*s*), and it produced a higher bile-secretion than had resulted from the hydrastin.

NECROPSY.—Decided redness of mucous membrane in the upper 12 inches of the small intestine; but there was only scanty evidence of purgation where the hydrastin had been injected.

Experiment 61. Dog that had fasted seventeen hours. Weight 13·6 kilogrammes (fig. 61).—Two grains of hydrastin, triturated with 2 cc. of bile, 1 cc. of rectified spirit, and 6 cc. of water were injected into the duodenum at *h*, and the same dose was again given at *h'*. Before the experiment was begun, it was observed that the animal was somewhat unhealthy, which accounts for the result being less definite in this than in the previous case: yet, ere the second dose was given, the bile-secretion had begun to rise, and after the second dose the increase was decided.

Experiment 60.		Experiment 61.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·40	0·230 cc.	0·7	
1·60		0·35	
1·65		0·60	
1·45		0·35	
h ——		0·30	
0·60		0·40	0·09 cc.
0·95		0·30	
1·60		0·35	
2·15		*h* ——	
1·90		0·17	
1·75		0·17	
h′ ——		0·15	
1·40		0·10	
0·85		0·30	
1·70		0·20	
3·55	0·386 cc.	0·15	
2·45		0·30	
2·30		0·35	
1·70		0·55	
2·15		*h′* ——	
1·00		0·60	
1·30		0·80	
s ——		0·80	
1·95		0·90	0·323 cc.
1·40		1·10	
3·95		1·15	
3·45		1·05	
		1·10	
		0·95	
		1·05	

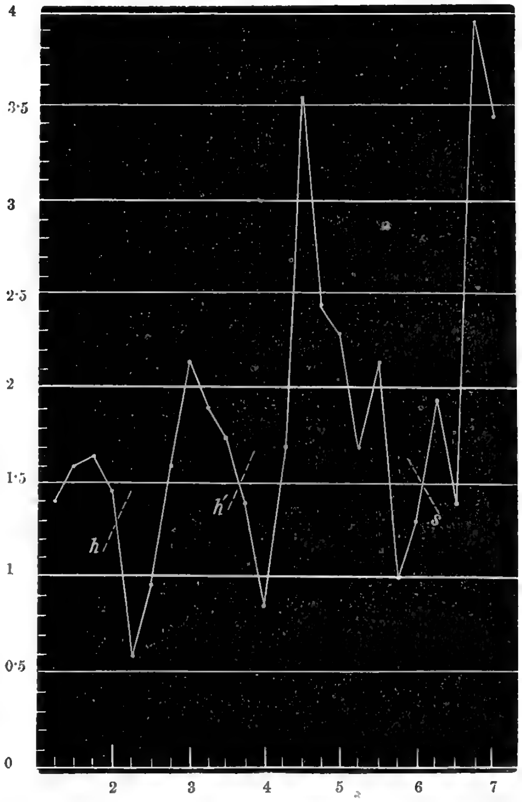

Fig. 60.—Secretion of bile before and after hydrastin and sodium salicylate. 2 grains of hydrastin in 2 cc. of rectified spirit, 1 cc. of bile, and 2 cc. of water injected into the duodenum at *h* and *h′*; 20 grains of sodium salicylate in 10 cc. of water injected into the lower portion of the intestine at *s*.

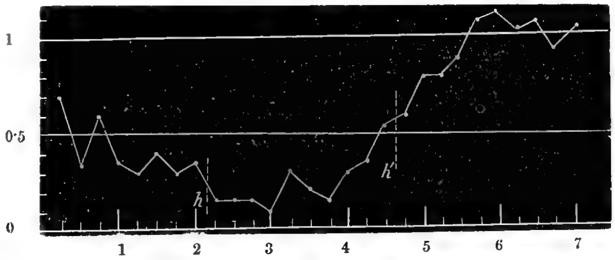

Fig. 61.—Secretion of bile before and after hydrastin. 2 grains of hydrastin in 2 cc. of bile, 1 cc. of rectified spirit, and 6 cc. of water injected into the duodenum at *h* and *h′*.

Necropsy.—Slightly increased redness of duodenal mucous membrane. Very slight evidence of purgative action.

Result of Experiments with Hydrastin.—It is a hepatic stimulant of considerable power, and a feeble intestinal stimulant. The fact shown in Table XXXI.—

that in Experiment 61 a dose relatively larger in proportion to the size of the animal than in Experiment 60 produced a smaller effect on the liver—seems only explicable by the fact that the subject of the former experiment was, as already stated, in an abnormal condition. Altogether, hydrastin appears to be a substance eminently worthy of the attention of the physician.

TABLE XXXI.

Hydrastin.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 60, .	2 with bile,	0·077	0·23 cc.	0·386 cc.
„ 61, .	2 „	0·147	0·09 cc.	0·323 cc.

ACTION OF RESIÑA JUGLANDIS OR "JUGLANDIN."

The juglandin employed in the following experiment was not an alkaloid, but an impure resin prepared by KEITH & Co. of New York, from the bark of the root of the butternut or white walnut (*Juglans cinerea*), after the same manner as menispermin (p. 210). Regarding the properties of the bark of the butternut, WOOD and BACHE (*Op.* x., p. 492) state that it is a mild cathartic, operating without pain or irritation, and resembling rhubarb in the property of evacuating without debilitating the alimentary canal. It was much employed during the late American civil war by DR RUSH and other army physicians. It is especially useful in habitual costiveness and dysentery. Nothing is stated regarding any influence on the liver. An extract of the bark is officinal in the United States. The dose of KEITH'S juglandin—the substance used in the following experiment —is from two to five grains.

Experiment 62. Dog that had fasted eighteen hours. Weight 21·1 kilogrammes (fig. 62).—Five grains of juglandin, triturated with 2 cc. of bile, 2 cc. of rectified spirit, and 5 cc. of water, were injected into the duodenum at *j*, and the same dose was repeated at *j'*. Both doses were followed by increased bile-secretion, which lasted four hours, and would probably have lasted even longer. Twenty grains of sodium salicylate in 10 cc. of water were injected into a lower part of the small intestine at *s*, and speedily caused a much greater hepatic excitement. Before any drug was given, the coefficient of secretion was 0·104 cc. of bile per kilogramme of body-weight per hour. After the first dose, it rose to 0·286 cc., and after the second to 0·327, showing that juglandin is a hepatic stimulant of moderate power. Indeed, it occasions a coefficient of secretion almost precisely the same as rhubarb (0·32 cc.) and leptandria (0·31 cc.).

Experiment 62.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.	
0·75	
0·65	
0·45	
0·45	
0·40	0·104 cc.
0·45	
0·45	
0·45	
0·65	
0·65	
j ——	
0·60	
0·85	
0·95	
1·80	0·286 cc.
1·40	
1·55	
1·30	
1·30	
j′ ——	
1·45	
1·75	
1·65	0·327 cc.
1·65	
1·85	
1·55	
1·60	
1·70	
1·65	
s ——	
1·95	
3·40	
3·75	

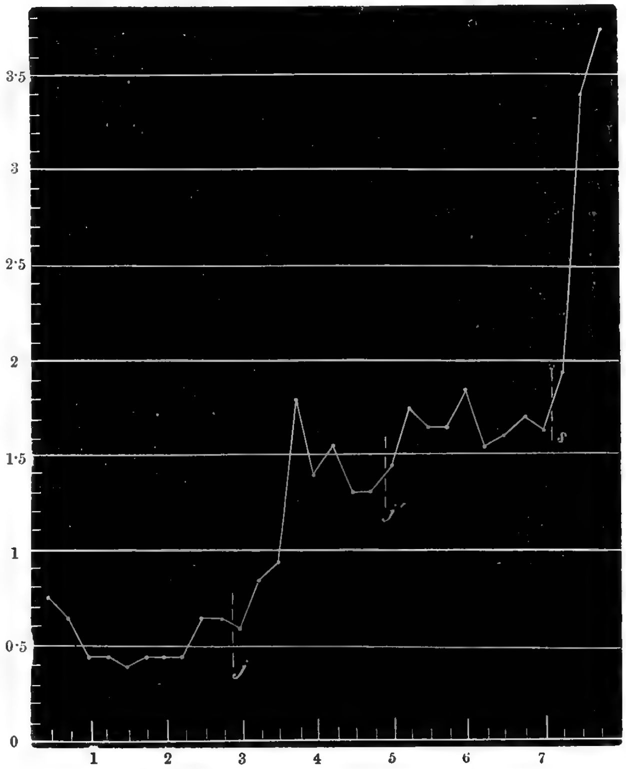

Fig. 62.—Secretion of bile before and after juglandin and sodium salicylate. 5 grains of juglandin in 2 cc. of rectified spirit, 2 cc. of bile, and 5 cc. of water injected into the duodenum at *j* and *j′*; 20 grains of sodium salicylate in 10 cc. of water injected into the lower portion of the intestine at *s*.

Necropsy.—Slightly increased redness of the duodenum, and slight purgation.

Result of Experiment with Juglandin.—It is a mild hepatic stimulant and a mild purgative, and seems eminently worthy of the attention of the physicians of this country.

ACTION OF BENZOIC ACID AND ITS COMPOUNDS.

Benzoic acid is said to act as a stimulant of the system generally, and particularly of the kidneys, mucous membrane of the bladder, and bronchial glands. It is nowhere stated to be a cholagogue. Yet it is sometimes used empirically in hepatic affections. Tanner, in his "Practice of Medicine," recommends ammonium benzoate in hepatic congestion with deficient urine, and benzoic acid in suppressed action of the liver and uræmia. Dr WADE of Birmingham employs benzoic acid in cases of catarrh of the bile-ducts; and we owe to the deep interest which he has taken in this research the valuable suggestion that we should endeavour to furnish a rational theory for the use of this agent in hepatic affections, by ascertaining whether or not it has the power of stimulating the liver. For a man, the dose of benzoic acid is from ten to thirty grains; that of benzoate of ammonia, from ten to twenty grains. Benzoate of soda has been employed by SOCQUET and BONJEAN (WOOD and BACHE, *Op.* x. p. 1471) as a remedy for gout and rheumatism; but we have not been able to ascertain the dose given. Probably the dose of the sodium is similar to that of the ammonium salt.

Experiment 63. Dog that had fasted seventeen hours. Weight 14·3 kilogrammes (fig. 63).—Fifteen grains of benzoic acid, partially dissolved in 20 cc. of water, were injected into the duodenum at *b*. A slight increase of the bile-secretion ensued; but it was not thought judicious to repeat the benzoic acid, owing to the fallacy that would have arisen from the effect of the large quantity of water required for its solution. Accordingly, twenty grains of sodium benzoate—an extremely soluble substance—dissolved in 10 cc. of water, were injected at *bs*, and a very powerful stimulation of the liver was the result, the coefficient of secretion rising as high as 0·646 cc. of bile per kilogramme of body-weight per hour.

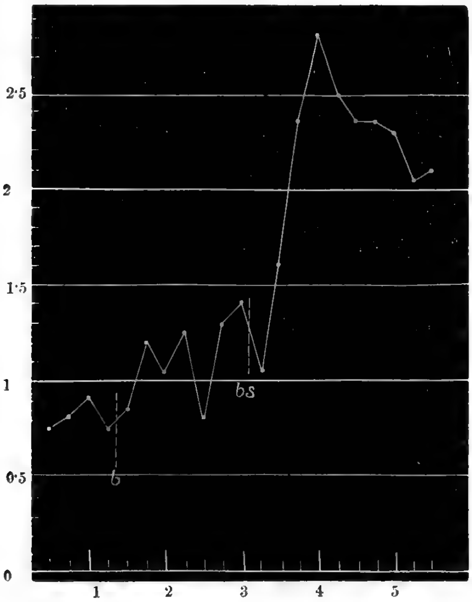

Fig. 63.—Secretion of bile before and after benzoic acid and sodium benzoate. 15 grains of benzoic acid in 20 cc. of water injected into the duodenum at *b*; 20 grains of sodium benzoate in 10 cc. of water injected at *bs*.

Experiment 63.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
0·75	0·223 cc.
0·80	
0·90	
0·75	
b ——	
0·85	
1·20	
1·05	
1·25	0·332 cc.
0·80	
1·30	
1·40	
bs ——	
1·05	
1·60	
2·35	
2·80	
2·50	0·646 cc.
2·35	
2·35	
2·05	
2·10	

Necropsy.—Very slight increase of redness of the duodenal mucous membrane. No purgation.

Experiment 64. Dog that had fasted eighteen hours. Weight 27·1 kilogrammes (fig. 64).—Twenty grains of ammonium benzoate, dissolved in 25 cc. of water, were injected into the duodenum at *b*. Within half an hour a powerful stimulation of the liver ensued that lasted five hours, and would probably have continued still longer had the experiment been continued. One-fifth of a grain of atropia sulphate, injected into the jugular vein at *a*, *a′*, and *a″*—three-fifths of a grain in all—did not antagonise the action of the benzoate.

Experiment 64.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
1·40	
1·35	
1·85	
1·55	
1·55	0·247 cc.
1·65	
1·70	
1·80	
b ——	
1·55	
3·63	0·544 cc.
4·05	
4·00	
3·10	
3·30	
3·20	
2·90	
2·65	
2·80	
2·55	
2·55	
2·45	
2·50	0·37 cc.
2·50	
2·50	
2·50	
2·65	
2·35	
a ——	
2·45	
a′ ——	
2·25	
2·30	
a″ ——	
2·40	
2·25	

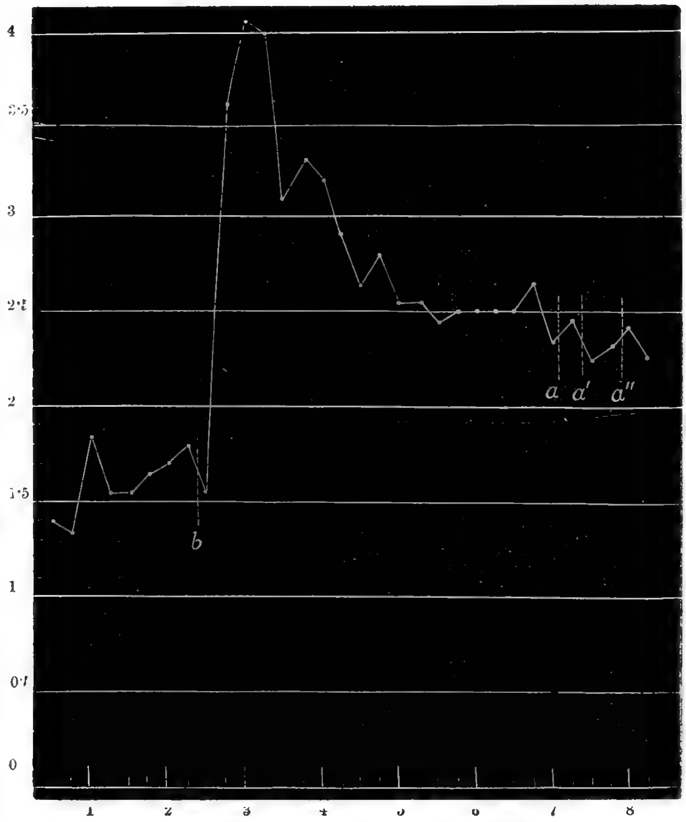

Fig. 64.—Secretion of bile before and after ammonium benzoate and atropia. 20 grains of ammonium benzoate in 25 cc. of water injected into the duodenum at *b*; one-fifth of a grain of atropia sulphate injected into the jugular vein at *a*, *a′*, and *a″*.

Necropsy.—There was no purgation, the intestine being perfectly dry; but the mucous membrane of the small intestine was considerably reddened to the extent of three feet below the pylorus.

A repetition of experiments so entirely satisfactory was unnecessary; nevertheless, in Experiment 70 there was a reason for giving sodium benzoate, and hepatic excitement again resulted from it.

TABLE XXXII.

	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per Hour.	
			Before.	After.
Sod. benzoate.—Ex. 63 .	20	1·320	0·223 cc.	0·646 cc.
Ammon. „ „ 64 .	20	0·737	0·247 cc.	0·544 cc.

Result of Experiments with the Benzoates.—Sodium benzoate and ammonium benzoate are both very powerful stimulants of the liver, but are not stimulants of the intestinal glands. It appears from the above experiments that the salt of sodium is a more powerful stimulant than that of ammonium; but the experiments are inconclusive on this point, because in Experiment 63 the sodium salt was assisted in its action by the previous administration of benzoic acid, and in addition the dose of the salt was greater in proportion to the size of the animal than in Experiment 64. Now that we have proved this action of these substances on the liver of the dog, a similar action on the human liver will doubtless be found; and probably the reason why it has hitherto escaped the attention of physicians is, that these substances, being hepatic but not intestinal stimulants, the hypersecretion of bile induced by them has not been revealed so as to attract attention. But probably, if a dose of sodium or ammonium benzoate were given at night, and a purely intestinal stimulant, such as magnesium sulphate, given in the morning, clear evidence would be found of the increased secretion of bile. These results, therefore, furnish a rational theory for the employment of the benzoates in congestion and some other affections of the liver. In view of the above discovery, we would ask the practical physician to consider the propriety of testing the effect of the benzoates in dysentery, for while they, like ipecacuan, powerfully stimulate the liver, and not the intestinal glands, they, unlike ipecacuan, induce no sickness or depression, but on the contrary, are nerve stimulants. Both the sodium and ammonium salts should be tried. It may also be well to observe that it would be perhaps advisable to increase the administration of the benzoates in ordinary catarrh, for they stimulate the liver as well as the bronchial glands, and the action of the liver in a common cold generally becomes somewhat defective.

One cannot leave the subject of benzoic acid without recalling WÖHLER and KELLER'S well-known discovery, that when benzoic acid is introduced into the economy, it is eliminated by the kidneys entirely in the form of hippuric acid. The fact that the latter, when treated with boiling hydrochloric acid, splits up into benzoic acid and glycin, suggested that the hippuric acid consequent upon the ingestion of benzoic acid arises from the union of that substance with glycin. Seeing that the two bile-acids—glycocholic and taurocholic acids—are conjugates of cholalic acid with glycin and taurin respectively, the thought naturally arose that the formation of hippuric acid by the conjugation of benzoic acid with glycin probably takes place in the liver. This theory of the seat of its formation was supported by KÜHNE and HALLWACHS (*Op.* xv.); but, on the other hand, MEISSNER and SHEPARD (*Op.* xvi.) maintained that the transformation of the benzoic acid takes place more in the kidneys than in the liver, and this opinion is supported by SCHMIEDEBERG and BUNGE (*Op.* xvii.). The evidence adduced by KÜHNE in favour of the liver as the exclusive seat of formation, or that by the other observers in favour of the kidney, need not here be entered into, for no light would thereby be thrown on the fact that, while benzoic acid is allying itself with glycin and carrying this substance into the urine, the hepatic cells are stimulated to produce more bile. In reviewing this subject, we have to express our regret that the bile was not analysed in the last two experiments, for the purpose of ascertaining whether or not its percentage amount of glycocholic acid was diminished, and to find out whether or not hippuric acid is excreted by the liver as well as by the kidney.*

ACTION OF SODIUM SALICYLATE.

Scarcely anything is known regarding the physiological actions of salicylic acid. BERTAGNINI (quoted in *Op.* xviii. p. 696) took 100 grains within two days in 4-grain doses, and felt nothing but ringing in the ears and some degree of deafness. He observed that the acid was excreted in the urine in the form of salicyluric acid. It is known that this is a conjugate of salicylic acid and glycin. The formula of benzoic acid is, $C_7H_6O_2$; that of salicylic acid, $C_7H_6O_3$. Their near chemical alliance and their similar behaviour towards glycin rendered it probable that salicylic acid, like benzoic acid, excites the hepatic cells. This substance has been lately much employed as a remedy in acute rheumatism. The dose for a man is from 15 to 20 grains.

Experiments 54, 60, and 62, already detailed, furnish abundant evidence of the remarkable powers of sodium salicylate as a stimulant of the liver, and other experiments yet to be described (Experiments 65, 67, 71A, and 73) furnish evidence still more striking; indeed, this substance is a certain hepatic stimulant, never failing, when placed in the duodenum, to excite the liver

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* Since the above was written we have ascertained that MOSLER (*Op.* iii. p. 45) found, from several experiments on a dog with a permanent fistula, that when 60 and even 90 grains of benzoic acid are administered by the mouth, no hippuric acid is found in the bile. It is singular that he did not collect and measure the bile secreted daily, otherwise he would doubtless have anticipated our discovery of the stimulating effect of benzoic acid on the liver.

within half-an-hour. Owing to its certain and speedy action, it has been repeatedly used in the later experiments merely to furnish an effect which might be readily compared with that produced by some other substance. Table XXXIII. gives the coefficients of bile secretion under its influence.

TABLE XXXIII.

Sodium Salicylate.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 73, .	20	1·00	0·178 cc.	0·565 cc.
" 54, .	25	1·55	2·260 cc.	0·664 cc.
" 65, .	20	2·15	0·329 cc.	0·890 cc.

Result of Experiments with Sodium Salicylate.—It is a very powerful hepatic stimulant in the dog. Its slight action on the intestine is probably the reason why its effect on the human liver has passed unobserved by the physician. We have given to a man 30 grains of sodium salicylate at night, and next morning a purely intestinal stimulant, such as magnesium sulphate, and we feel convinced that there was an increased discharge of bile. We commend this point to the attention of physicians.

ACTION OF AMMONIUM PHOSPHATE AND OF TANNIC ACID.

The similar effects produced on the liver by the sodium and ammonium salts of salicylic acid, led us to think again of the stimulating effect of sodium phosphate, and induced us to test the action of ammonium phosphate. It is employed in cases of chronic gout, and in urinary affections where uric acid calculi exist or threaten. Nothing has been hitherto known regarding its action on the liver, probably because it is not an intestinal stimulant; and, therefore, the increased secretion of bile—which it probably induces in man as it certainly does in the dog—has passed unobserved. The dose for a man is from 5 to 20 grains.

The first experiment with this substance yielded a negative result; but it has been thought right to discard it, because the ammonium phosphate was injected after liquor bismuthi into the same part of the intestinal canal.

Experiment 65. Dog that had fasted seventeen hours. Weight 9·7 kilogrammes (fig. 65).—20 grains of ammonium phosphate dissolved in 22 cc. of water, were injected into the duodenum at *a*. The subsequent increased bile-secretion was decided and prolonged. Since tannin is employed as an astringent in cases of diarrhœa, 20 grains, dissolved in 20 cc. of warm water, were injected into a fresh portion of the small intestine (*t*); but, as it did not affect the bile-secretion, it was not thought worth while to repeat the dose. 20 grains of sodium salicylate, in 10 cc. of water, were then injected into a fresh portion of the small intestine (*s*), and, within half-an-hour, its never-failing effect was evident. Obviously it stimulated the liver much more powerfully than the ammonium phosphate. At the beginning of the experiment, the coefficient of secretion was 0·19 cc. per kilogramme of body-weight per hour; a fair average for a fasting dog. After the ammonium phosphate, it rose to the unusually high figure of 0·634 cc.; but after the sodium salicylate, it rose still higher to 0·89 cc. The result of this experiment being apparently so unequivocal, it was not thought necessary to repeat it. Nevertheless, considering the small size of the animal (9·7 kilos.), and that the dose was the maximum dose for a man,

Experiment 65.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.	
0·35	
0·50	0·19 cc.
0·45	
0·40	
0·50	
a ——	
0·75	
0·80	
1·10	
1·25	
1·10	
1·25	
1·30	
1·50	
1·50	0·634 cc.
1·55	
1·60	
1·50	
1·20	
1·05	
1·00	
0·90	
t ——	
0·90	
0·85	0·329 cc.
0·80	
0·80	
0·75	
s ——	
1·25	0·89 cc.
2·50	
2·65	
2·25	

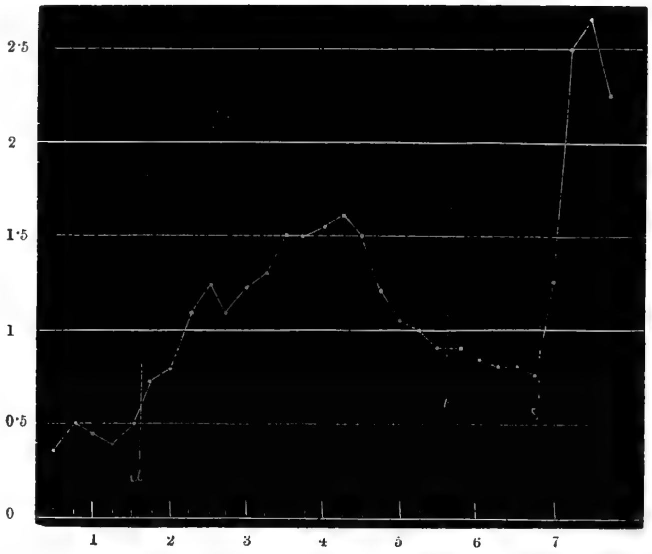

Fig. 65.—Secretion of bile before and after ammonium phosphate, tannin, and sodium salicylate. 20 grains of ammonium phosphate in 22 cc. of water injected into the duodenum at *a*; 20 grains of tannin in 20 cc. of water injected at *t*; 20 grains of sodium salicylate in 10 cc. of water injected at *s*.

it seems reasonable to regard the effect of the ammonium phosphate in this case as perhaps unduly exaggerated.

NECROPSY.—Nothing notable observed in the intestine.

Result of Experiment with Ammonium Phosphate and Tannic Acid.—Ammonium phosphate is a powerful hepatic stimulant, but not so powerful as sodium salicylate. It is not an intestinal stimulant. Probably now that we have directed attention to the matter, it will be found to be a stimulant of the human liver also. Tannin does not appear to affect the liver.

ACTION OF ACETATE OF LEAD.

The well-known astringent effect of lead acetate in cases of diarrhœa renders it desirable to know whether or not it has the power of diminishing the secretion of bile. RÖHRIG (*Op.* vi. p. 270) experimented with acetate of lead, and found that 0·6 gramme (9·2 grains), dissolved in 4 ounces of warm water, and injected into the small intestine of a dog, diminished the secretion of bile. The erroneous nature of some of RÖHRIG'S results, due to his very imperfect mode of experiment—as pointed out in the introduction—rendered necessary a re-investigation of the effects of lead acetate.

It has already been stated that, in Experiment 53A, the administration of 8 grains of lead acetate was followed by a diminution of the bile-secretion, but that the result was of an equivocal nature. In Experiment 54, 10 grains produced no effect. In Experiment 57, a first dose of 8 grains, with a second dose of 12 grains, was indeed followed by a diminished bile-secretion; but, as stated in the description of that experiment, the result was entirely equivocal, and therefore other experiments were obviously required.

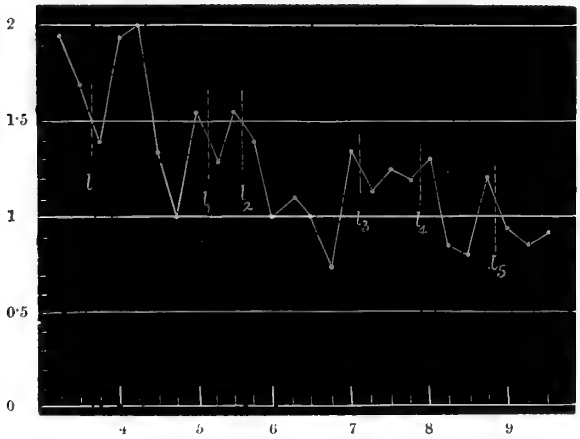

Fig. 66.—Secretion of bile before and after lead acetate. 2 grains in 15 cc. of water injected into the duodenum at l and l_1; 4 grains in 32 cc. of water at l_2; 4 grains in 15 cc. of water at l_3; 8 grains in 15 cc. of water at l_4; and 10 grains in 15 cc. of water at l_5 (30 grains given in all).

Experiment 66. Dog that had fasted seventeen hours. Weight not ascertained (fig. 66).—Owing to great difficulty in introducing the biliary cannula, and consequent serious disturbance of the bile-duct and its surroundings, the secretion of bile became, as mostly happens in such a case, very irregular; so much so, indeed, that the record of the first three hours is omitted from the chart. Two grains of lead acetate in 15 cc. of water were injected in the duodenum at l and l_1; 4 grains in 32 cc.

of water at l_2; 4 grains in 15 cc. of water at l_3; 8 grains in 15 cc. of water at l_4; and 10 grains in 15 cc. of water at l_5. Thirty grains were given in all. The irregularity of secretion rendered the experiment unsatisfactory, and the discovery that the acetate of lead used in this and the previous experiments was impure, necessitated another experiment.

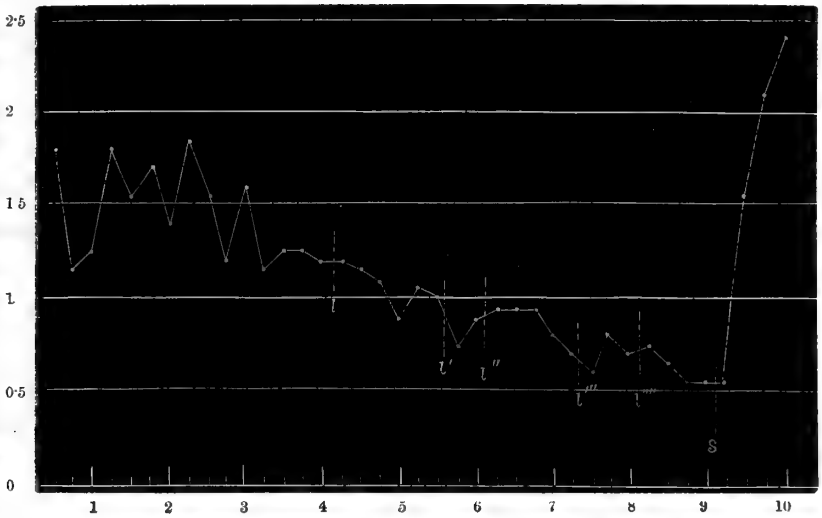

Fig. 67.—Secretion of bile before and after lead acetate and sodium salicylate. 10 grains of lead acetate in 20 cc. of water injected into the duodenum at l and l'; 10 grains in 10 cc. of water at l'', l''', and l''''; 20 grains of sodium salicyate in 10 cc. of water injected into the duodenum at s.

Experiment 67.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·8		0·75	
1·15		0·90	
1·25		l'' ——	
1·80		0·95	
1·55		0·95	
1·70		0·95	
1·40		0·80	
1·85		0·70	
1·55		l''' ——	
1·20		0·60	
1·60		0·80	
1·15		0·70	
1·25	0·331 cc.	l'''' ——	
1·25		0·75	0·171 cc.
1·2		0·65	
l ——		0·55	
1·2		0·55	
1·15		s ——	
1·10		0·55	
0·90		1·55	0·452 cc.
1·05		2·10	
1·00		2·40	
l' ——			

Experiment 67. Dog that had fasted eighteen hours. Weight 14·6 kilogrammes (fig. 67).—Ten grains of pure lead acetate, dissolved in 10 cc. of distilled water, were injected into the duodenum at *l*, *l′*, *l″*, *l‴*, and *l⁗*; 50 grains in all being given. The decided fall in secretion towards the close of this experiment is abnormal, and may fairly be ascribed to a depressant effect of the lead; but it is obvious that the first doses did not produce the effect which might have been anticipated from RÖHRIG's experiments. That the liver was not exhausted, however, and was capable of increased action, was proved by injecting into the duodenum 20 grains of sodium salicylate dissolved in 10 cc. of water. Although it was the ninth hour of the experiment, the biliary secretion became greatly accelerated, and reached a point decidedly higher than it had been at the beginning of the experiment. All the more, therefore, may the previously diminished secretion be ascribed to the depressant action of the lead; while it is obvious that an ordinary dose of sodium salicylate can excite the liver thus poisoned and depressed.

Result of Experiments with Lead Acetate.—In large doses, it has a depressant effect on the secretion of bile. Sodium salicylate can overcome that effect. The obstinate constipation observed in cases of lead-poisoning may, to some extent, be owing to the depressant effect of lead on the liver; but it is probably chiefly owing to a depressant action on the intestinal glands; for, in view of the astringent effect of a dose of from 1 to 4 grains in diarrhœa, it seems likely, from the above experiments, that it affects the intestinal canal more than the liver. It is a remarkable fact that, of all the substances employed in this research, lead acetate is the only one which depresses the action of the liver without producing purgation. It seems to be a direct hepatic depressant. As previously explained, every purely intestinal purgative agent depresses hepatic action, in a manner which is probably, however, purely indirect, and to which allusion will again be made in the sequel.

ACTION OF JABORANDI.

Jaborandi being a powerful stimulant of the salivary and sweat glands, we thought it desirable to ascertain its influence on the liver. The mean dose for a man is a watery infusion of sixty-four grains of the leaves.

Experiment 68. Dog that had fasted eighteen hours. Weight 21·5 kilogrammes (fig. 68).—Eight cc. of water with 2 cc. of bile were injected into the duodenum at *b*, and 8 cc. of a concentrated aqueous infusion containing the active principle of 64 grains of jaborandi leaves were injected at *j*, and the same dose was again given at *j′*. Powerful salivation began half-an-hour after the first dose (at *s*), and it is to be observed that shortly afterwards the bile-secretion also underwent a slight increase, that became more marked after the second dose.

Necropsy.—Ninety-seven cc. of liquid in the small intestine (30 cc. had been injected), but whether most of it had been secreted by the pancreas or by Lieberkühn's follicles was undetermined. There was no unusual redness of the intestinal mucous membrane.

Experiment 68.		Experiment 68A.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·40		1·80	
1·42		1·70	
1·40		1·67	
b ——		1·70	
1·40	0·265 cc.	*b* ——	
1·45		1·70	0·314 cc.
1·40		1·72	
j ——		1·65	
1·40		1·70	
1·40		*j* ——	
s ——		1·70	
1·40		1·60	
1·50		*s* ——	
1·50		1·60	
1·55		1·70	
1·50		1·60	
1·60		1·75	
1·45		1·80	
j′ ——		1·75	
1·50		1·90	
1.50		1·95	
1·60		2·00	0·365 cc.
1·70	0·310 cc.	1·80	
1·60		2·00	
1·72		2·05	
1·55		1·85	
1·80		1·72	
1·55		1·60	
1·65		*j′* ——	
1·50		1·50	
1·40		1·52	
1·70		1·62	
1·50		1·67	
1·35		1·70	
		1·75	

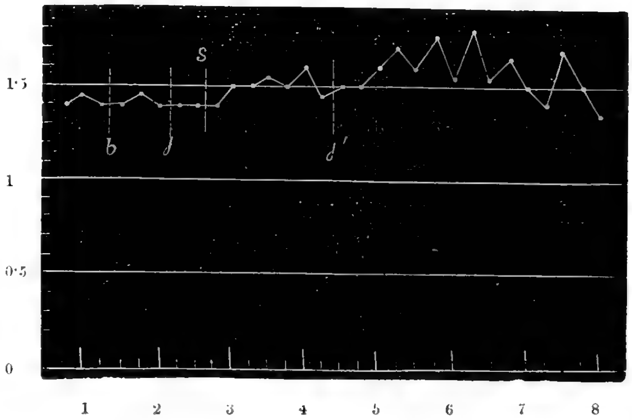

Fig. 68.—Secretion of bile before and after jaborandi. 2 cc. of bile and 8 cc. of water injected into the duodenum at *b*; 8 cc. of infusion of jaborandi with 2 cc. of bile injected at *j* and *j′*; salivation began at *s*.

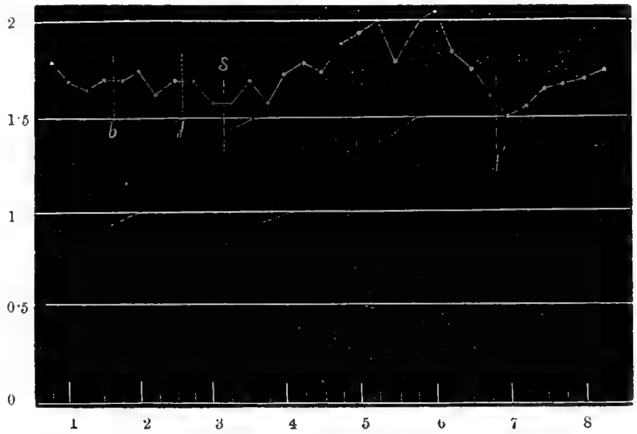

Fig. 68A.—Secretion of bile before and after jaborandi. At *b*, 2 cc. of bile and 10 cc. of water; at *j* and *j′* the same fluid, with 10 cc. infusion of 75 grains of jaborandi leaves injected into the duodenum. Salivation began at *s*.

Experiment 68A. Dog that had fasted eighteen hours. Weight 21·5 kilogrammes (fig. 68A).—Ten cc. of water with 2 cc. of bile were injected into the duodenum at *b*, and the same fluid, with 10 cc. of aqueous infusion of jaborandi, was injected at *j* and again at *j′*. As each cubic centimetre of the infusion contained the active principle of 7½ grains of the leaves, 150 grains had been given. Salivation began half-an-hour after the first dose, and soon thereafter the bile-secretion rose, but to no great extent. It was observed in this experiment that the *bronchial glands were much stimulated* by the jaborandi, the respiratory cannula being completely obstructed by a watery mucus, which must have been secreted in the bronchi and trachea.

Necropsy.—The jaborandi had traversed the whole length of the small intestine, which contained 107 cc. of a clear greenish fluid without mucous flakes. Thirty-six cc. of fluid had been injected; but how much of the remainder had been secreted by the pancreas and how much by Lieberkühn's follicles could not be determined.

Result of Experiments with Jaborandi.—In doses that were much more than sufficient to excite the salivary glands, jaborandi produced only a slight increase in the biliary secretion. It is therefore to be regarded as a very feeble hepatic stimulant.

Action of Sulphate of Manganese.

It is stated by Pareira (*Op.* xix. I. p. 635) that "C. G. Gmelin tried the effect of the sulphate of the protoxide of manganese on animals, and found that it caused vomiting, paralysis with convulsions, and inflammation of the stomach, small intestines, liver, spleen, and heart. He notices as a remarkable fact, the extraordinary secretion of bile produced by it, and which was so considerable that nearly all the intestines were coloured by it, and the large intestines had a wax-yellow colour communicated to them." At the suggestion of Pareira (*loc. cit.*), its effects on the human subject were tested by Mr Ure, who found that, in doses of from 60 to 120 grains, it acts as a purgative and cholagogue. In a recent communication to the *Lancet* (1878, i. 882), Dr R. H. Goolden states that he has been in the habit of using the substance as a cholagogue for more than thirty years. He finds that, in doses of from ten to twenty grains, it produces large bilious evacuations. Ten grains he regards as a sufficient dose for ordinary purposes. This he dissolves in a tumbler of water, and adds some citrate of potash or magnesia. These statements rendered it desirable for us to test the action of this substance by our method of experiment.

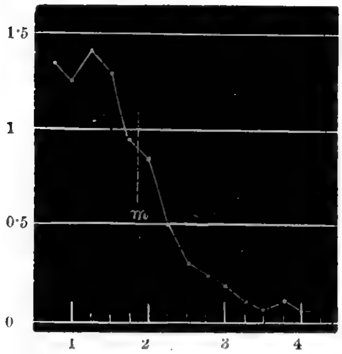

Fig. 69.—Secretion of bile before and after sulphate of manganese. 60 grains of manganese sulphate in 30 cc. of water injected into the duodenum at *m*.

Experiment 69. Dog that had fasted eighteen hours. Weight 15 kilogrammes (fig. 69).—Thinking, from Pareira's statement of the amount given to the human subject by Ure, that 60 grains of manganese sulphate would not be too large a dose for a dog, we injected that amount in 30 cc. of water into the duodenum at *m*. So far from any increase of the bile-secretion resulting, there was a decided fall, the secretion coming nearly to a standstill. The weak pulse of the animal suggested that collapse had been occasioned by the drug, and the necropsy fully confirmed the idea that too much had been given. The fall of secretion, however, was in the first instance indirectly due to the effects of the powerful purgation that was induced, though the very low secretion at the close was, in all probability, due to collapse.

NECROPSY.—Evidence of powerful purgation in the upper third of small intestine. Very violent irritation of the mucous membrane of this region of the gut, the surface of which was covered with a yellowish-white pulpy matter, as if the epithelium had been dissolved by a caustic alkali.

Experiment 70. Dog that had fasted eighteen hours. Weight 17·7 kilogrammes (fig. 70).—As the dose in the previous case had evidently been too large, only 20 grains of manganese sulphate were given, in the same manner as before, in this instance (*m*). But there was not the slightest rise in the bile-secretion; on the contrary, there was a decided fall, as is the rule under the influence of a substance that produces purgation without exciting the liver. It now came to be the question, Would the bile-secretion rise in spite of the purgative drain from the portal vein, if a hepatic stimulant were administered? To determine this, 21 grains of sodium benzoate in 15 cc. of water were injected into the duodenum at *s*; and, in spite of the disadvantageous circumstance of its being introduced into a column of intestinal juice actively being secreted, it excited the liver to secrete more bile, showing that the liver could be excited by a substance possessed of the property of so doing.

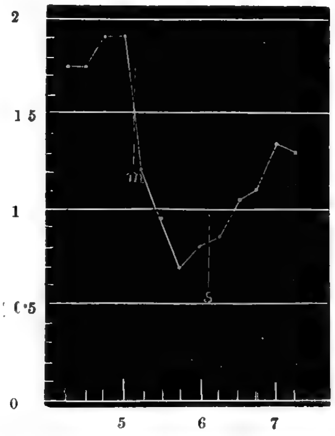

Fig. 70.—Secretion of bile before and after manganese sulphate and sodium benzoate. 20 grains of manganese sulphate in 15 cc. of water injected into the duodenum at *m*; 21 grains of sodium benzoate in 15 cc. of water injected at *s*.

NECROPSY.—Copious watery purgation throughout the whole length of small intestine, whose mucous membrane was, however, scarcely at all reddened. The dose had, therefore, been efficient as an intestinal, but not as a hepatic, stimulant.

Results of Experiments with Manganese Sulphate.—Experiments 69 and 70 entirely bear out the statement that manganese sulphate is an intestinal stimulant, but lend no support to the idea that it is a hepatic stimulant. The effect on the biliary secretion is, indeed, similar to that of magnesium sulphate (Experiments 18 and 19), or any other purely intestinal stimulant; that is, it diminishes the biliary secretion, probably by draining the portal system. Yet

Dr Goolden's statements are explicitly to the effect (*lib. cit.*) that the same result was not produced by sulphate of magnesium as by sulphate of manganese. We cannot, of course, from the above experiments, deny that the manganese salt is a cholagogue in man; but, looking to the general harmony between our observations on the dog and those on man, we think we are entitled to throw very grave doubts upon the idea that manganese sulphate excites the human liver. It might, indeed, be maintained that it has the power of inducing contractions of the gall-bladder and larger bile-ducts, and of thus increasing the amount of bile in the dejections; but we can only commend to the attention of physicians Dr Goolden's positive observations as to the increased amount of bile in the dejections of man, and our negative results as to any stimulating effect on the bile-secreting mechanism of the dog.

Action of Morphia.

As morphia has the well-known power of arresting diarrhœa and of producing constipation, it is desirable to know whether this is to be ascribed to its effect on the intestine alone, or also to a power of diminishing the secretion of bile.

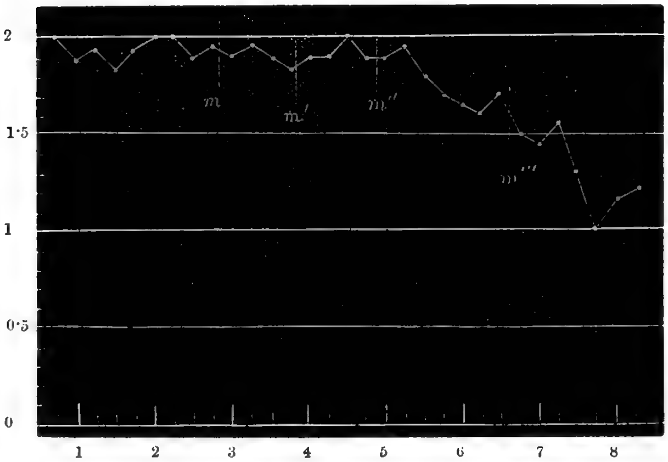

Fig. 71.—Secretion of bile before and after morphia hydrochlorate. 1 grain with 2 cc. of bile and 1 cc. of water injected into the duodenum at *m*, *m'*, *m''*, and *m'''*.

Experiment 71. Dog that had fasted eighteen hours. Weight 33 kilogrammes (fig. 71).—One grain of morphia hydrochlorate in 3 cc. of bile and water was injected into the duodenum at *m*, *m'*, *m''*, and *m'''*, 4 grains being given in all. The first two doses had no obvious effect on the bile-secretion; but it began to fall after the third, and continued to do so after the fourth, doses. As it was impossible to know, from this single experiment, whether or not this fall in the secretion was due to the morphia, a second experiment was performed.

Necropsy.—The mucous membrane of the small intestine was almost perfectly dry.

Experiment 71A. Dog that had fasted eighteen hours. Weight 19·9 kilogrammes (fig. 71A).—One grain of acetate of morphia in 5 cc. of water was injected into the duodenum at *m*, and 2 grains in 10 cc. of water were injected at *m′*. No diminution of secretion was the result; in short, the morphia did not appear to affect the secretion. As it seemed desirable to know whether or not the liver of an animal so narcotised could be excited by an appropriate stimulant, 20 grains of sodium salicylate in 10 cc. of water were injected into the duodenum at *s*. Powerful and prolonged excitement of the liver was the result.

Experiment 71A.

	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
	cc.	
	1·15	
	0·85	
	0·80	0·15 cc.
	0·70	
	0·70	
	0·80	
m		
	0·95	
	1·10	
	0·95	
m′		
	0·90	
	0·85	0·178 cc.
	0·75	
	1·05	
	0·90	
s		
	1·05	
	3·05	0·565 cc.
	3·35	
	2·45	
	2·40	
	2·15	
	2·30	
	2·30	
	2·30	
	2·60	
	2·60	

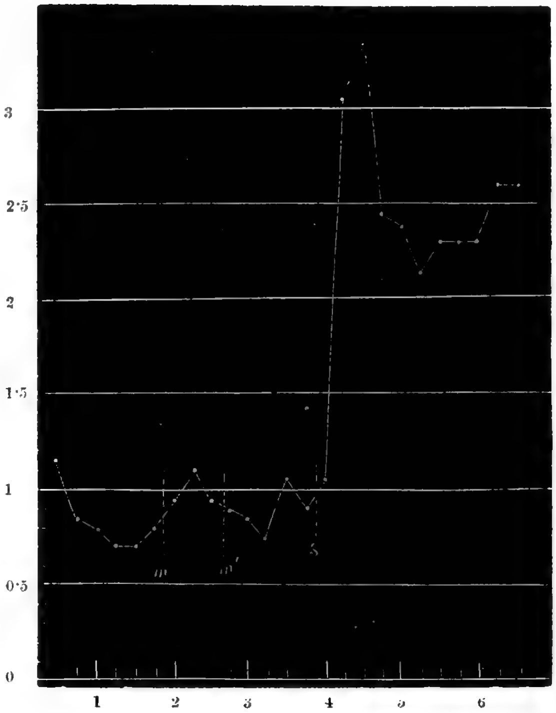

Fig. 71A.—Secretion of bile before and after morphia and sodium salicylate. 1 grain of morphia acetate in 5 cc. of water injected into the duodenum at *m*; 2 grains in 10 cc. of water at *m′*; 20 grains of sodium salicylate in 10 cc. of water injected into the duodenum at *s*.

Necropsy.—Slightly increased redness of the duodenal mucous membrane. Evidence of slight purgative action in the upper part of the small intestine.

Result of Experiments with Morphia.—Three grains of morphia acetate did not affect the secretion of bile.

ACTION OF HYOSCYAMUS.

As extract of hyoscyamus is often administered with cholagogue substances, it is important to know whether or not it diminishes the secretion of bile. The dose of this substance for a man is from 5 to 10 grains.

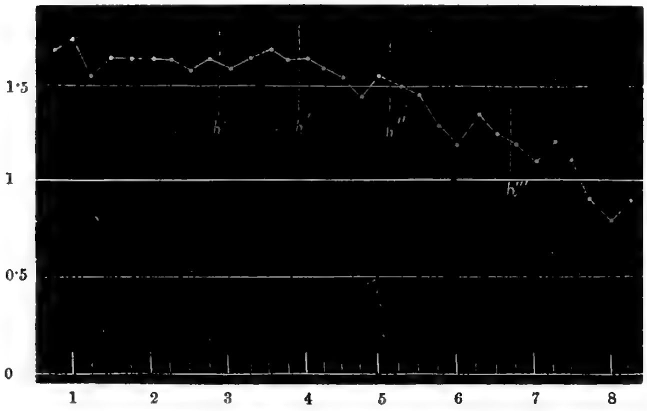

Fig. 72.—Secretion of bile before and after hyoscyamus. 2 grains of extract of hyoscyamus with 3 cc. of water injected into the duodenum at *h*, *h′*, *h″*, and *h‴*.

Experiment 72. Dog that had fasted eighteen hours. Weight 21 kilogrammes (fig. 72).—2 grains of aqueous extract of hyoscyamus in 3 cc. of water were injected into the duodenum at *h*, *h′*, *h″*, and *h‴*, 8 grains being given in all. It was impossible, from this single experiment, to say whether or not the fall in the secretion was due to the hyoscyamus; but the unusually high coefficient of secretion in the earlier part of the experiment (0·311 cc. per kilogramme per hour) favoured the conclusion that the fall was not due to the drug.

Experiment 72.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·7		1·45	
1·75		1·55	
1·55		*h″* ——	
1·65		1·50	
1·65		1·45	
1·65		1·30	
1·65	0·311 cc.	1·20	
1·60		1·35	
1·65		1·25	
h ——		*h‴* ——	
1·60		1·20	
1·65		1·10	
1·70		0·90	
1·65		0·80	
h′ ——		0·90	
1·65		0·80	0·176 cc.
1·60		0·90	
1·55			

NECROPSY.—Mucous membrane of small intestine pale and dry.

Experiment 73. Dog that had fasted eighteen hours. Weight 16·8 kilogrammes (fig. 73).—To decide the point left in doubt by the previous experiment, larger doses of the drug were administered. Eight grains of extract of hyoscyamus triturated with 1 cc. of bile and 10 cc. of water were injected into the duodenum at *h*, and the same dose was injected into a lower part of the intestine at *h′*. It is difficult to account for the slight rise of secretion that followed both doses. It may be safely assumed that it was due neither to the bile nor to the water. At all events, there was no fall of secretion, notwithstanding the administration of sixteen grains of the drug.

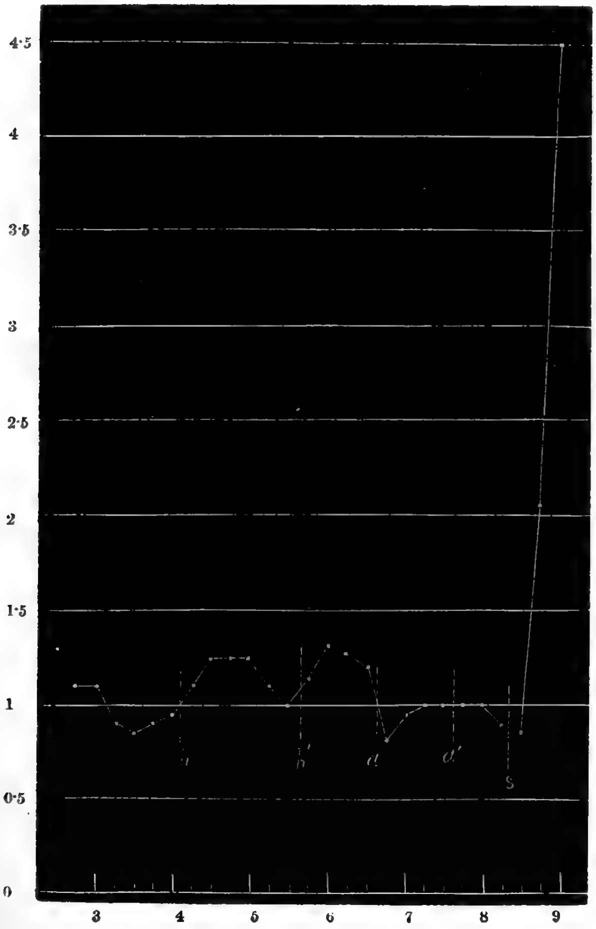

Fig. 73.—Secretion of bile before and after hyoscyamus and absolute alcohol. 8 grains of extract of hyoscyamus in 10 cc. of water and 1 cc. of bile injected into the duodenum at *h*; the same, injected into a lower part of the small intestine, at *h′*; 5 cc. of absolute alcohol in 20 cc. of water injected into the small intestine at *a*; 8 cc. of absolute alcohol in 32 cc. of water injected into the small intestine at *a′*; 20 grains of sodium salicylate in 10 cc. of water injected into the duodenum at *s*.

Experiment 73.

	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
	cc.	
	1·30	
	1·10	
	1.10	
	0·90	0·214 cc.
	0·85	
	0·90	
	0·95	
h		
	1·10	
	1·25	0·288 cc.
	1·25	
	1·25	
	1·10	
	1·00	
h′		
	1·15	
	1·30	
	1·25	
	1·20	
a		
	0·80	
	0·95	
	1·00	0·231 cc.
	1·00	
a′		
	1·00	
	1·00	
	0·90	
s		
	0·85	
	2·05	
	4·50	

As the experiment was entirely conclusive regarding the effect of hyoscyamus, it was proposed to investigate the action of pure alcohol; accordingly 5 cc. of absolute alcohol, diluted with 32 cc. of water, were injected into a fresh portion of the small intestine, and, as there was no notable effect, 8 cc. of absolute alcohol in 32 cc. of water were injected into another part of the gut. Notwithstanding the administration of 13 cc. of alcohol (219 minims), the bile secretion was virtually unaffected. It was now sought to determine what such a liver could do if stimulated. Twenty grains of sodium salicylate in 10 cc. of water were injected into the duodenum at *s*, and speedily thereafter the bile-secretion was enormously increased, and that so late as the ninth hour of the experiment.

Result of Experiments with Hyoscyamus.—Sixteen grains of extract of hyoscyamus, prepared according to the "British Pharmacopœia," did not notably affect the biliary secretion, and did not prevent such a stimulant as sodium salicylate from augmenting it. From observations on the human subject, we are also able to state that hyoscyamus does not seem to interfere with the stimulating effect of euonymin on the liver, and very probably it may be safely given with all hepatic stimulants that are also intestinal stimulants, and happen to cause griping.

Action of Alcohol.

It is a matter of common opinion that alcoholic drinks affect the action of the liver; but, whether their hepatic effects may be ascribed to the alcohol, ethers, or other substances they contain, no one has hitherto sought to determine. The results of the preceding experiment already go far to determine the question as regards pure alcohol; but as hyoscyamus had in that experiment been previously administered, it was desirable to perform another experiment in which nothing but pure diluted alcohol should be administered.

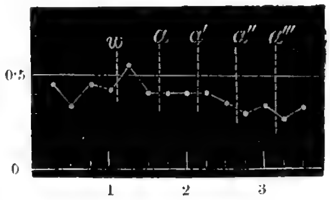

Fig. 74.—Secretion of bile before and after alcohol. At *w* 15 cc. of water; at *a*, *a'*, *a''*, *a'''*, 5 cc. of absolute alcohol with 15 cc. of water injected into the stomach through an œsophagus tube.

Experiment 74. A small dog (not weighed) that had fasted eighteen hours (fig. 74).—Fifteen cc. of water were injected into the stomach through an œsophagus tube (*w*); then 5 cc. of absolute alcohol diluted with 15 cc. of water were injected into the stomach in the same manner at *a*, *a'*; *a''*, and *a'''*, 20 cc. (338 minims) being given in all.

Result of Experiments with Alcohol.—In Experiment 73, 13 cc. of absolute alcohol, and in Experiment 74, 30 cc. of absolute alcohol, moderately diluted and introduced into the alimentary canal, did not produce any apparent effect on the biliary secretion. These experiments, however, furnish no evidence of what might be the effects of the prolonged action of alcohol on the liver; and, in consideration of the great labour and length of this research, we could not undertake experiments designed to show the effects of various sorts of alcoholic drinks, or of the substances other than alcohol which they contain. Such research could scarcely be of great practical importance, for we already know that certain alcoholic drinks—such as ale, stout, &c.—tend to produce "biliousness;" and, by experiments on the human subject, we have ascertained that the condition, thus induced, may be cured by giving iridin or euonymin, substances which powerfully stimulate the liver. As far as they go, however, our experiments show that *pure alcohol* has, at all events, *no immediate* action on the liver of the dog.

ACTION OF MERCURIAL SALTS.

Calomel, and mercury in the form of blue pill, are the two preparations of mercury commonly employed for the purpose of inducing purgative action. The most generally received opinion regarding the action of calomel as a cholagogue is thus expressed by CHRISTISON (*Op.* xii. p. 505):—" The cathartic action of calomel and other mercurials is uncertain, unless other cathartics are united with them. Their action on the bowels is believed to be always attended by an increased discharge of bile from the gall-bladder." But although this has long been the prevalent opinion, some physicians have doubted the cholagogue property of calomel, and on that account several attempts have been made to determine its action by experiments on animals. NASSE (*Op.* i. p. 158) seems to have been the first to make the attempt. He established a permanent biliary fistula in the manner already indicated (p. 3), and he found that calomel increased the absolute quantity of fluid bile, but diminished its solid constituents. By a similar method KÖLLIKER and MÜLLER (*Op.* ii.) found that 4 grains of calomel given to a dog diminished the secretion of bile. MOSLER (*Op.* iii.), adopting also the method of permanent fistula, found that even when large doses of calomel were administered, not a trace of mercury was found in the bile. SCOTT (*Op.* iv.) gave to a dog with a permanent biliary fistula 3 grains, 6 grains, and 12 grains of calomel on four separate occasions. He collected the bile continuously before, during, and after each dose of the mercurial, and he found but one result, viz., a diminution in the amount of bile and bile-solids secreted after the administration of these doses. SCOTT'S experiment appears to have been very carefully conducted. Its result was so much at variance with the prevalent opinion regarding the action of calomel in man, that some authorities alleged that there must be some difference between the action of mercurials on man and on the dog. Impressed with the necessity for obtaining precise information with regard to this point and others, HUGHES BENNETT organised the committee to which reference has already been made. The committee settled beyond all possibility of doubt that mercury produces in the dog the same general effects as in man (*Op.* v. p. 201). When small but increasing doses of corrosive sublimate were injected under the skin for several days in succession, salivation occurred, the breath became fœtid, the gums ulcerated, emaciation ensued, and in dogs without biliary fistulæ (when therefore the bile was discharged into the intestine), the drug set up profuse diarrhœa, while in dogs with biliary fistulæ there was no diarrhœa. The significance of this fact struck no one at the time, but the experiments hereafter to be detailed furnish what is probably the true explanation (see p. 244). The committee further found (*Op. cit.* p. 214) that when calomel was administered to dogs with permanent biliary fistulæ in doses of one-twelfth of a grain given from six to fourteen times daily, and in doses of 2 grains from two to six times daily, it did not increase the biliary secretion, nor did it produce purgation; but when given in doses of 10 grains once a day, it produced purgation and diminished the biliary secretion. More recently experiments were performed by Röhrig (*Op.* vi. p. 254), who found by the method of temporary fistula, that when "calomel was administered to dogs in large doses (20 grains), it rarely happened that the secretion of bile was recalled after it had come to a standstill, although it increased the secretion when it was only diminishing." The imperfections of Röhrig's method render such a statement of very little value. Our method of experiment being better adapted to afford accurate data, we accordingly performed the following experiments :—

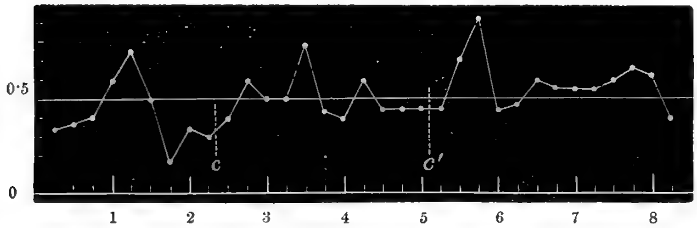

Fig. 75.—Secretion of bile before and after calomel given without bile. 10 grains calomel in 7 cc. water injected into duodenum at *c*, and again at *c′*.

Experiment 75.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.		cc.	
0·30		0·45	0·091 cc.
0·32	0·103 cc.	0·45	
0·35		0·45	
0·60		*c′* ——	
0·76		0·45	
0·50	0·067 cc.	0·72	0·133 cc.
0·17		0·97	
0·35		0·45	
0·30		0·47	
c ——		0·60	0·116 cc.
0·40	0·102 cc.	0·57	
0·60		0·55	
0·50		0·57	
0·50		0·60	0·12 cc.
0·80	0·114 cc.	0·72	
0·45		0·65	
0·40		0·40	
0·60			

Experiment 75. Dog that had fasted eighteen hours. Weight 19·6 kilogrammes (fig. 75).—10 grains of calomel in 7 cc. water were injected into the duodenum at *c*, and the same dose was repeated at *c′*.

Necropsy.—There was evidence of a profuse purgative effect, the small intestine containing a large quantity of a thick greyish fluid with greenish flakes. The mucous membrane was pale throughout the greater part of its extent, but at intervals in the duodenum there were limited areas of redness.

The post-mortem examination in this case was not made until fourteen hours after death.

In Experiment 75 the administration of 20 grains of calomel in two doses of 10 grains was followed by a powerful purgative effect and by a slight increase in the bile-secretion; but considering that the coefficient of secretion never rose above 0·133 cc., it is evident that the increased activity of the liver was very trifling. Yet one would be apt to be misled by such an experiment as this, had we, after the manner of Röhrig, failed to show the amount of bile secreted in relation to the weight of the animal. Judging from subsequent experiments, it can scarcely be doubted that the trifling increase of secretion in this experiment had nothing to do with the calomel.

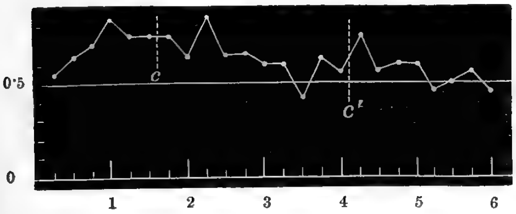

Fig. 75A.—Secretion of bile before and after calomel given without bile. 10 grains calomel in 3 cc. water injected into duodenum at *c*, and the same dose repeated at *c′*.

Experiment 75A.

Secretion of bile per 12″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·57		0·60	0·31 cc.
0·65		0·40	
0·70	0·43 cc.	0·65	
0·85		0·57	
0·75		*c′* ——	
0·75		0·75	0·36 cc.
c ——		0·52	
0·75		0·60	
0·65		0·60	
0·87		0·45	0·27 cc.
0·62		0·50	
0·67		0·55	
0·60		0·45	

Experiment 75A. Dog that had fasted eighteen hours. Weight 7 kilogrammes (fig. 75 A).—10 grains of calomel in 3 cc. water were injected into the duodenum at *c*, and again at *c′* (20 grains given in all .

Necropsy.—The upper third of the small intestine was semi-distended with a brown, somewhat clear, viscous fluid, with patches of green, thus affording evidence of purgative action. The gastric mucous membrane was pale, and contained some viscous fluid of a brownish colour, with a patch of green matter clinging to the mucous membrane near to the pylorus, which was evidently due to the entrance of calomel from the duodenum, for a little unchanged calomel was perceptible at the margin of the patch. The cause of the brown colour of the fluid was not apparent. The necropsy was in this case performed fifteen hours after death.

The exceptionally high secretion in Experiment 75A was probably due to the circumstance that the animal was a young one. In proportion to the weight of the animal, more bile is secreted by a young than by a full-grown dog. The administration of calomel was followed by decided purgation and by diminished bile-secretion.

Experiment 75B. Dog that had fasted eighteen hours. Weight 12·9 kilogrammes (fig. 75B).—The secretion of bile was unfortunately very irregular in the early part of the experiment. 10 grains of calomel in 9 cc. water were injected into the duodenum at *c*, and again at *c* ; 20 grains being given in all.

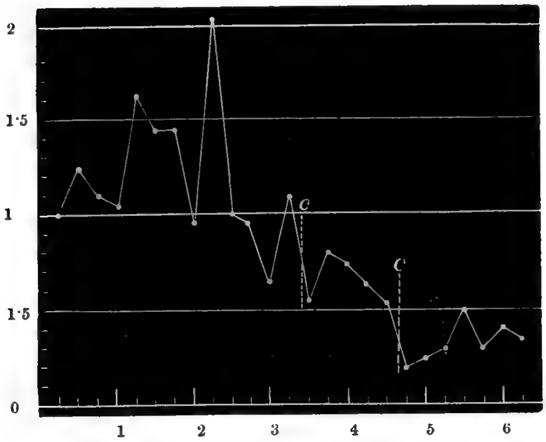

Fig. 75B.—Secretion of bile before and after calomel given without bile. 10 grains calomel in 9 cc. water injected into duodenum at *c*, and the same dose repeated at *c*′.

Experiment 75B.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog : per hour.
cc.		cc.	
1·00		*c* ——	
1·25		0·56	
1·12		0·80	0·29 cc.
1·07		0·74	
1·65		0·62	
1·45		0·54	
1·42		*c*′ ——	
0·97		0·20	
2·05		0·28	
1·00	0·28 cc.	0·32	
0·94		0·50	0·12 cc.
0·62		0·30	
1·12		0·40	
		0·36	

A profuse purgative action was the result, but the bile-secretion was only lowered.

Necropsy.—Stomach contained a colourless mucous fluid, with here and there a green patch of calomel that had entered it through the pylorus. The upper half of the small intestine contained a large quantity of a greyish fluid with green patches, thus affording evidence of a powerful purgative effect. The mucous membrane in this region of the intestine was very vascular.

The general result of the three preceding experiments is that calomel did not stimulate the liver, although it did not fail to stimulate the intestinal glands. But it is to be observed that the calomel was introduced into the duodenum suspended in water, it could not come into contact with bile in the intestine, for owing to the fasting condition of the animal previous to the establishment of the fistula, there was no bile there. Calomel is insoluble in water, and as Headland (*Op.* xx. p. 380) had pointed out that it is to a slight extent soluble in bile, we were led to suppose that possibly its non-action on the liver in these cases might have resulted from the absence of bile from the intestinal canal. And it was apparent that this source of fallacy had also vitiated every experiment that had been performed by previous observers. We accordingly performed the two following experiments, in which the calomel was mixed with bile, and then injected into the duodenum, and we gave smaller doses than in the preceding experiments.

Experiment 76. Dog that had fasted seventeen hours. Weight 14·7 kilogrammes (fig. 76).—2·5 cc. water and 0·5 cc. bile were injected into the duodenum at *b*, and 2 grains of calomel in the same fluid at *c*, *c′*, *c″*, and *d*: 8 grains being given in all. Unfortunately, the secretion of bile was very irregular. The main result of the experiment was diminished biliary secretion, still the slight increments of secretion that followed the first, second, and fourth doses, rendered a repetition of the experiment desirable.

NECROPSY.—The upper half of the small intestine contained evidence of decided purgation. Its mucous membrane was considerably congested.

Experiment 76.		Experiment 76A.	
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·05		1·80	
0·85		1·90	
0·65		1·80	
0·80		1·70	
0·65		1·70	
0·55		1·65	0·258 cc.
b ——		*b* ——	
0·55	0·125 cc.	1·65	
0·35		1·70	
0·40		1·65	
c ——		*c* ——	
0·55	0·196 cc.	1·70	
0·60		1·70	
0·80		1·65	
0·75		1·62	
0·45		*c′* ——	
c′ ——		1·60	0·248 cc.
0·35		1·62	
0·50	0·129 cc.	1·57	
0·55		1·62	
0·55		*c″* ——	
0·30		1·62	
c″ ——		1·60	
0·15		1·55	
0·25		1·60	
0·20		*c‴* ——	
0·10		1·50	
0·15		1·40	
d ——		1·50	
0·65	0·108 cc.	1·40	
0·40		c^4 ——	
0·25		1·40	
0·20		1·30	0·204 cc.
0·30		1·40	
		1·30	
		1·25	

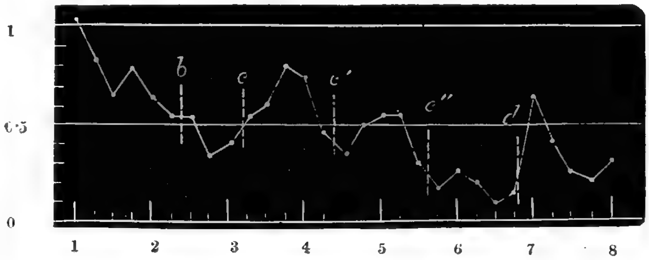

Fig. 76.—Secretion of bile before and after calomel given with bile. 0·5 cc. bile and 2·5 cc. water injected into duodenum at *b*. 2 grains calomel in the above fluid injected into duodenum at *c*, *c′*, *c″*, and *d*, respectively.

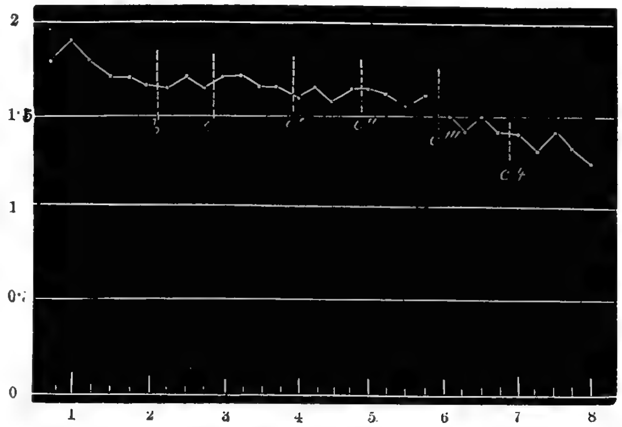

Fig. 76A.—Secretion of bile before and after calomel given with bile. 0·5 cc. bile and 2·5 cc. water injected into duodenum at *b*. 1 grain calomel in the above fluid injected into duodenum at *c*, *c′*, *c″*, *c‴*, c^4, respectively.

Experiment 76A. Dog that had fasted seventeen hours. Weight 25·7 kilogrammes (fig. 76A).—2·5 cc. water and 0·5 cc. bile were injected into the duodenum at *b*, and 1 grain of calomel in the same fluid was injected at *c*, *c′*, *c″*, *c‴*, and c^4: 5 grains being given in all. The bile-secretion was never increased.

NECROPSY.—The upper half of the small intestine contained 187 cc. of a viscous fluid with grey flakes; thus affording evidence of strong purgation. The vascularity of the mucous membrane was decidedly increased.

Result of Experiments with Calomel mixed with Bile.—The biliary secretion in Experiment 76A was so regular, and the doses of calomel so graduated, that its result may be regarded as conclusively showing, that calomel when mixed with bile and placed in the duodenum, does not excite the liver, although it powerfully stimulates the intestinal glands. *The addition of bile to the calomel made therefore no difference in the result.*

As is well known, MIAHLE (*Chimie Appliquée*) ascribed all the effects of calomel, and other mercurial preparations, to the production of mercuric chloride, by the action of the alkaline chlorides in the secretions of the alimentary canal, more especially in the gastric juice. This theory has, however, been strongly opposed by BUCHHEIM, ŒTINGER, and WINCKLER (referred to by WOOD in *Op.* xi. p. 330), on the grounds that, at a temperature so low as that of the body, calomel undergoes no transformation into mercuric chloride in a solution of alkaline chlorides. Nevertheless, one must remember that the gastric juice contains free hydrochloric acid. The amount is only 0·02 per cent. in the juice of man, mixed with saliva: in that of the dog, the amount is 0·031 per cent. (C. SCHMIDT). When MIAHLE wrote, the free acid of the gastric juice was thought to be lactic; therefore, the effect of very dilute hydrochloric acid on calomel, at the body temperature, has not hitherto been investigated. As no conclusion could be legitimate in the absence of definite information on this point, we performed the following experiment:—

Experiment 77.—Calomel was washed with ether, the filtrate tested with caustic potash, and proved to contain no mercuric chloride. Of the calomel—thus ascertained to be pure—we placed three grammes in 500 cc. distilled water containing 0·02 per cent. anhydrous hydrochloric acid, and submitted the whole to a constant temperature of 100° Fahr.—the temperature of the stomach—for thirty-six hours. The fluid was then filtered, concentrated, and tested with sulphuretted hydrogen. A distinct precipitate—first white, then changing to yellow, and finally to black—was obtained, thus proving the presence of corrosive sublimate. Judging from the precipitate, the amount was considerable; but a large quantity of calomel had been employed, and it had been acted on by the acid for a lengthened period. We repeated the experiment, using the same amount of calomel, and acid fluid, but keeping it only seventeen hours at the temperature of the body. The fluid was then filtered, the filtrate evaporated, the residue dried and weighed, and it was found that three grammes of calomel had yielded 17 milligrammes of mercuric chloride. Under similar circumstances, 5 grains of calomel—the ordinary dose for a man—would, if digested seventeen hours with about 50 cc. acid fluid, have yielded $\frac{1}{35}$ grain mercuric chloride. Whether or not so minute a quantity of the latter substance is likely to affect the human liver will be considered in the sequel. Calomel is usually taken at bed-time on an empty stomach. We do not know if it can call forth a secretion of gastric juice sufficient to exert an appreciable influence upon it; but in any case, it probably does not remain in the stomach more than five or six hours at the utmost. We however postpone for the present the further consideration of this point.

Obviously, our next duty was to ascertain whether or not corrosive sublimate has the power of stimulating the liver.

Experiment 78. Dog that had fasted seventeen hours. Weight 8·8 kilogrammes (fig. 78).—Into the duodenum there were injected the following fractions of a grain of corrosive sublimate dissolved in 3 cc. water: $\frac{1}{20}$ at *a*, $\frac{1}{15}$ at *b*, $\frac{1}{15}$ at *c*, $\frac{1}{20}$ at *d*, $\frac{1}{15}$ at *e*, $\frac{1}{10}$ at *f*: two-fifths of a grain being given in all.

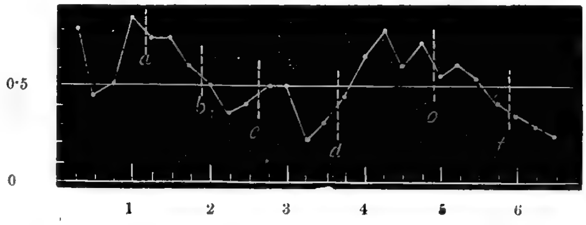

Fig. 78.—Secretion of bile before and after mercuric chloride (corrosive sublimate) given without bile. *a* $\frac{1}{20}$ grain, *b* $\frac{1}{15}$ grain, *c* $\frac{1}{15}$ grain, *d* $\frac{1}{20}$ grain, *e* $\frac{1}{15}$ grain, *f* $\frac{1}{10}$ grain mercuric chloride in 3 cc. water injected into duodenum. ($\frac{2}{5}$ grain in all.)

Necropsy. — The mucous membrane of about fourteen inches of the upper portion of the small intestine was much congested. In the upper part of the duodenum there were minute hæmorrhagic extravasations. There was evidence of a very slight purgative effect.

The increase of secretion that followed the fourth dose of mercuric chloride was so slight, that on the whole the result must be regarded as negative. Considering the solubility of mercuric chloride in water,—and the striking contrast between it and calomel in this respect,—it is not at all probable that the negative result in Experiment 78 was due to the non-absorption of the mercurial salt. Possibly it was simply owing to the circumstance that, in small—somewhat weak dogs—such as that employed in the above experiment, the most certain cholagogues sometimes fail to stimulate the liver, probably because of the depressing effect of the preliminary operation adopted in these experiments. At the same time, we resolved in the next experiment to add some bile to the mercuric chloride solution, in case its presence might facilitate absorption, or, at any rate, in order that the conditions encountered in the intestine in a normal case, might be more exactly imitated.

Experiment 78a. Dog that had fasted nineteen hours. Weight 16·2 kilogrammes (fig. 78a).—2·5 cc. water and 0·5 cc. bile were injected into the duodenum at *b*, and $\frac{1}{16}$ grain corrosive sublimate in the same fluid was injected at *c*, and the same dose was repeated at *c′*. At the end of two hours the bile-secretion began to rise, and rose still higher after the second dose.

NECROPSY.—The mucous membrane of the upper ten inches of the small intestine was decidedly reddened, and there was evidence of a very slight purgative action in this portion of the intestine.

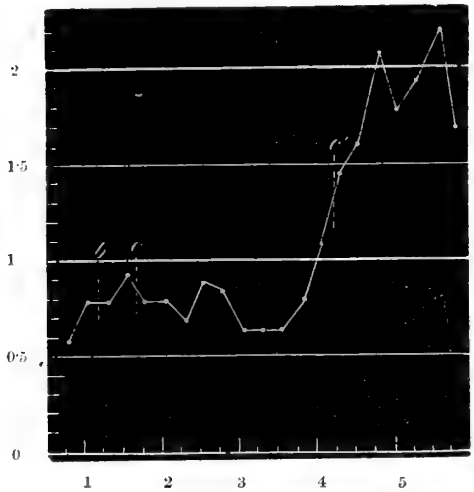

Fig. 78A.—Secretion of bile before and after mercuric chloride given with bile. 0·5 cc. bile and 2·5 cc. water injected into duodenum at *b*. The same fluid with $\frac{1}{16}$ grain mercuric chloride injected into duodenum at *c* and again at *c'* ($\frac{1}{8}$ grain given in all).

Experiment 78A.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·60	0·171 cc.	0·65	
0·80		0·65	
b ——		0·80	
0·80		1·1	
0·95		*c'* ——	
c ——		1·45	
0·80		1·60	
0·80		2·10	
0·70		1·80	0·472 cc.
0·90		1·95	
0·85		2·20	
0·65		1·70	

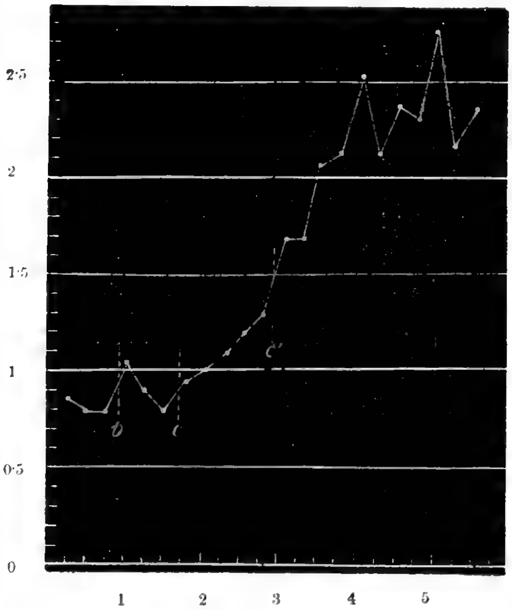

Fig. 78B.—Secretion of bile before and after mercuric chloride given with bile. *b*, *c*, and *c'* indicate precisely the same as in fig. 78A.

Experiment 78B.			
Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
0·85		*c'* ——	
0·80		1·70	
0·80	0·202 cc.	1·70	
b ——		2·10	
1·05		2·15	
0·90		2·55	
0·80		2·15	
c ——		2·40	
0·95		2·35	0·557 cc.
1·00		2·80	
1·10		2·20	
1·20		2·40	
1·30			

Experiment 78B. Dog that had fasted nineteen hours. Weight 17·5 kilogrammes (fig. 78B).—In this experiment the same doses were given and in the same manner as in the preceding experiment. The result was similar, a decided increase of secretion following the second dose.

NECROPSY.—The state of the duodenum and its contents was precisely similar to that described in the preceding experiment.

Experiments 78A and 78B prove conclusively, and in a very striking manner, that mercuric chloride is a hepatic stimulant; and that it is a powerful one is shown by the fact that in Experiment 78A, $\frac{1}{8}$ grain raised the bile-secretion per kilogramme of body-weight to 0·472 cc. per hour; while in Experiment 78B it raised the secretion to 0·557 cc. per kilogramme per hour.

The contrast between the last two experiments with mercuric chloride and those with calomel is remarkable, both as regards the effect on the *liver*, and on the *intestine;* for while the mercuric chloride powerfully excited the liver, but scarcely affected the intestinal glands, notwithstanding its immediate contact with the latter, the calomel did not stimulate the liver, but did powerfully excite the intestinal glands.

This startling result so clearly established by these experiments is a striking proof of the value of this method of investigation as an auxiliary to clinical observations on man.

To render these experiments still more complete, we in the next two cases injected into the duodenum a minute dose of mercuric chloride along with calomel and bile. These experiments are valuable in showing the very remarkable stimulation of the liver that followed an unusually small dose of the mercurial.

Experiment 78C. Dog that fasted seventeen hours. Weight 9·9 kilogrammes (fig. 78c).—0·5 cc. bile and 2 cc. water were injected into the duodenum at *b*, and $\frac{1}{20}$ grain of corrosive sublimate and 1 grain of calomel in the same fluid were injected at *m*.

Experiment 78c.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·2	0·48 cc.	1·65	
1·2		1·80	0·72 cc.
b —		1·75	
1·1		1·85	
1·3		1·75	
m —		1·50	
1·4		1·35	
1·65		1·15	
1·50		1·15	

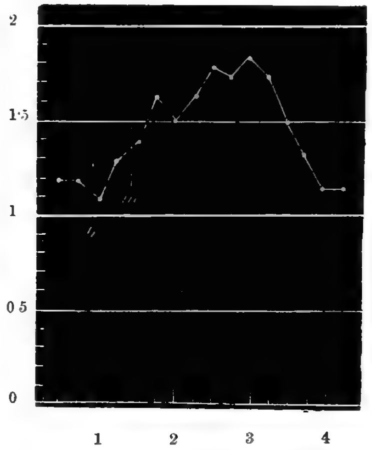

Fig. 78c.—Secretion of bile before and after mercuric chloride and calomel given with bile. 0·5 cc. bile and 2 cc. water injected into duodenum at *b*. $\frac{1}{20}$ grain mercuric chloride and 1 grain calomel in the same fluid injected into duodenum at *m*.

NECROPSY.—Slightly increased vascularity of mucous membrane of duodenum. No purgation.

In the above experiment, the bile-secretion per hour rose to 0·72 cc. per kilogramme of body-weight, but the secretion was so high—0·48 cc.—before the drug was given, that it was difficult to know exactly how to regard the very high figure first mentioned. Another experiment was therefore desirable.

Experiment 78D. Dog that had fasted seventeen hours. Weight 18·4 kilogrammes (fig. 78D).—$\frac{1}{20}$ grain of corrosive sublimate and 1 grain of calomel mixed with 2 cc. water and 0·5 cc. bile were injected into the duodenum at *m*, and the same dose was repeated at *m′* and at *m″*.

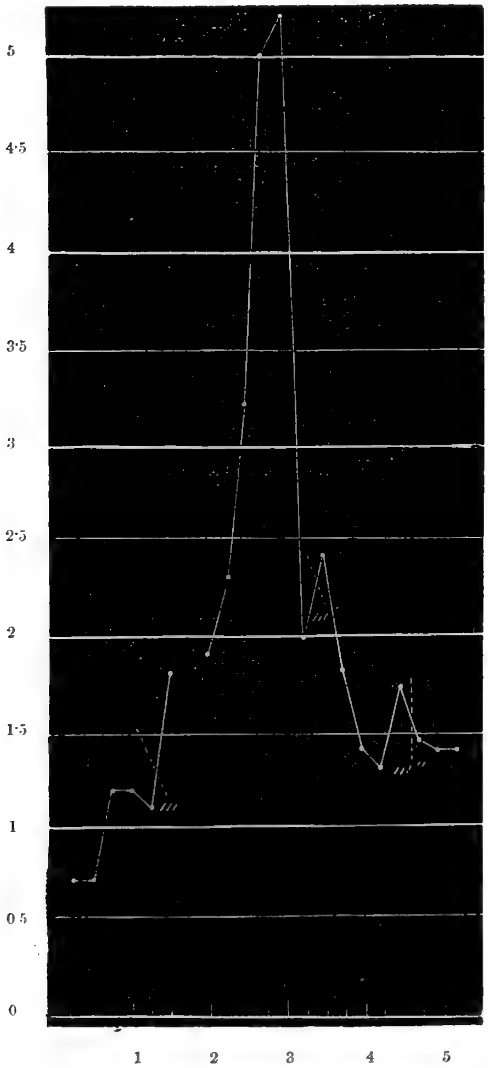

Fig. 78D.—Secretion of bile before and after mercuric chloride and calomel given with bile. $\frac{1}{20}$ grain mercuric chloride with 1 grain calomel in 0·5 cc. bile and 2 cc. water injected into duodenum at *m*, *m′*, and *m″* respectively.

Experiment 78D.

	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
	cc.	
	0·7	
	0·7	0·228 cc.
	1·2	
	1·2	
	1·1	
m		
	1·8	
	lost	
	1·9	
	2·3	0·85 cc.
	3·2	
	5·0	
	5·2	
	2·0	
m′		
	2·4	
	1·8	
	1·4	
	1·3	
	1·7	
m″		
	1·45	
	1·4	
	1·4	

NECROPSY.—Considerable irritation of the mucous membrane of the upper fourth of small intestine. The contents of this portion of the canal indicated considerable purgative action.

The increase of bile-secretion in Experiment 78D is very remarkable, not only for its absolute extent, but also because of the smallness of the dose that occasioned it. The amount of bile secreted per kilogramme of body-weight rose to the very high figure of 0·85 cc. per hour. The effect of so small a dose as $\frac{1}{20}$ grain of corrosive sublimate in this experiment is very remarkable, for the animal was rather larger than those employed in Experiments 78A and 78B, where $\frac{1}{16}$ and even $\frac{1}{8}$ grain had not so powerful an effect. Considering the result of Experiment 76A, it is not in the least likely that the addition of one grain of calomel to the dose of the mercuric chloride had anything to do with the difference in the result. We can only suggest, by way of explanation, that possibly in some cases the liver is more susceptible to a mercurial stimulus than it is in others.

With the mercuric chloride we had given bile in every case save in Experiment 78, and that was the only instance where the result was negative; we therefore thought it desirable to perform another experiment, with mercuric chloride given without bile.

Experiment 78E.

Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.	Secretion of bile per 15″.	Secretion of bile per kilogramme of dog: per hour.
cc.		cc.	
1·80		1·35	
1·70		1·50	
1·50		1·50	
1·85		1·55	
1·45	0·388 cc.	1·75	
1·35		1·30	
1·30		1·65	
1·10		1·70	
c ——		1·50	
1·15		1·30	
0·80		c″ ——	
1·45		1·90	0·50 cc.
lost		1·70	
1·25		1·65	
1·30		1·45	
1·55		1·50	
1·10		1·45	
c′ ——		1·60	

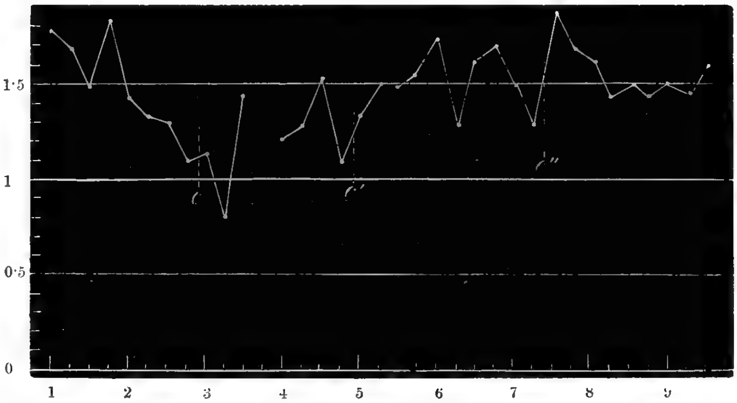

Fig. 78E.—Secretion of bile before and after mercuric chloride given without bile. $\frac{1}{8}$ grain mercuric chloride in 6 cc. water injected into duodenum at c, c′, and c″. ($\frac{3}{8}$ grain given in all.)

Experiment 78E. Dog that had fasted seventeen hours. Weight 13·4 kilogrammes (fig. 78E).—$\frac{1}{8}$ grain corrosive sublimate in 6 cc. water was injected into the duodenum at *c*, and the same dose was repeated at *c*′ and *c*″. The liver was stimulated, the coefficient of bile-secretion rising as high as 0·5 cc. But the experiment is inconclusive, for a reason mentioned in the necropsy.

NECROPSY.—The upper fourth of the small intestine contained a considerable quantity of somewhat dark fluid, looking as if bile had been injected. Possibly some bile had, in this case, escaped from the bile-ducts into the intestine during the performance of the operation. The presence or absence of bile would have been determined by testing the fluid for bile-pigment, but unhappily a portion set aside for that purpose was lost.

This experiment therefore is inconclusive as regards the point at issue, viz., whether or not mercuric chloride is absorbed from the intestine without the presence of bile. But we felt that it would scarcely be justifiable to perform yet another experiment to settle the point; for it is to the last degree improbable that bile is necessary, and probably no one will feel inclined to maintain that it is.

TABLE XXXIV.

Mercury.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Secretion of Bile per Kilogramme of Body-weight per hour.	
			Before.	After.
Experiment 78A, Mercuric Chloride, ...	$\frac{1}{8}$ with bile,	0·0077	0·17 cc.	0·47 cc.
Experiment 78B, Mercuric Chloride, ...	$\frac{1}{8}$,,	0·0071	0·20 cc.	0·55 cc.
Experiment 78C $HgCl_2$. $HgCl$.	$\frac{1}{20}$,, 1 ,,	0·005 0·101	0·48 cc.	0·72 cc.
,, 78 D $HgCl_2$. $HgCl$.	$\frac{1}{20}$,, 1 ,,	0·0027 0·054	0·22 cc.	0·85 cc.

Result of Experiments with Mercuric Chloride.—These experiments conclusively prove that mercuric chloride is a powerful hepatic stimulant in the dog. Probably—now that attention is specially directed to the subject—it will also be found to stimulate the liver of man; for the experiments already referred to (p. 105), that were carried out by the author for BENNETT'S Committee, showed that the general effects of mercuric chloride on the dog are similar to those observed in man. Doubtless the converse will be found to hold.

In the series of experiments, just referred to, on the production of mercurialism in the dog, the mercuric chloride was always injected subcutaneously, and in two experiments on the action of this substance on the biliary secretion, performed for that committee, the drug was given in the same manner. This mode of administering a substance for the purpose of acting on the liver was faulty, and its results are not fairly comparable with those of the ordinary method, where the substance is placed in the alimentary canal, from which its molecules are absorbed into the radicles of the portal vein, and so pass to the liver in a much more concentrated stream than they possibly can when the substance passes first into the general and then into the portal circulation.

With regard to these two experiments, HUHGES BENNETT stated in the report (*Op.* v. p. 221) "that corrosive sublimate when given" [*subcutaneously*] "in small doses, gradually increased in strength, does not augment the biliary secretion, but that it diminishes it the moment the dose reaches a strength sufficient to deteriorate the general health." The latter part of the statement was warranted by the results of both experiments. But the first part, though true as regards one of the experiments, was certainly untrue as regards the other (*Op. cit.* p. 212, Table XIII.), where an unequivocal increase of bile-secretion took place when the dose of mercuric chloride, given subcutaneously, was raised from one-sixth grain *once* a day to one-sixth grain *twice* a day (*loc. cit.* June 9th and 10th). The reporter of the experiments on that occasion overlooked the important fact here stated, and deduced the above general conclusion from misleading results, arrived at by taking the daily average quantity of bile secreted during too prolonged a period.

Results of Experiments with Calomel.—With regard to calomel, we have proved the following:—(1) That calomel in doses of 10 grains, 5 grains, or 2 grains, several times repeated, when placed, *without bile*, in the duodenum of a fasting dog, produces a purgative effect, varying with the dose; but, so far from increasing the secretion of the bile, usually diminishes it, just as happens when any other substance that is not a hepatic stimulant—*e.g.* magnesium sulphate—is administered. (2) That when calomel is *mixed with bile*, and then introduced into the duodenum, there is no difference in the result, even when, as in Experiment 76A, the calomel is given in 1 grain doses several times repeated, and the chance of acting on the liver, previous to supervention of the depressing effect of purgation, thus allowed. (3) That if 5 grains of calomel be subjected at 100° Fahr. for *seventeen hours* to the action of dilute hydrochloric acid, of the same strength as that of the human gastric juice, not more than $\frac{1}{35}$ grain of mercuric chloride is produced.

The question now arises, seeing that calomel does not usually remain in the human stomach for more than a night, probably not more than from five to six hours, is it likely that even so much as $\frac{1}{35}$ grain of mercuric chloride is produced from the ordinary dose of 5 grains, and if it is, what effect may it be supposed to have on the human liver? It must be borne in mind, however, that we are here on dangerous ground, for we are inclining to reason about the action of the gastric juice itself from experiments on the action of dilute hydrochloric acid, and a solution of alkaline chlorides. It would clearly be more conclusive if we could substitute direct experiment for mere inference. We are in a position to do this.

As regards the dog, it is evident that the only link wanting to complete our chain of evidence is, that we should place the calomel in the *stomach* instead of the *duodenum,* and thus render the case analogous to that of the human subject as regards the administration of this drug. With regard to the cases of calomel, we did indeed seriously think for a time that the negative effect of the calomel on the liver might possibly have been due to the circumstance, that the drug was introduced directly into the duodenum, and thus escaped the action of the gastric juice.

Experiment 78F.—Into the stomach of a curarised dog, that had fasted the usual time, we injected 5 grains of calomel in water. The injection was made with a fine syringe, through the *gastric wall,* in order that the whole of it might certainly reach the interior of the viscus. Injection through an œsophagus tube was avoided, because a substance so insoluble as calomel would certainly have clung to the interior of the tube, and would thus have been partly lost.

The result of the experiment was entirely negative, both as regards the liver and the intestinal glands. This was readily explained by the fact, that at the necropsy the calomel was found apparently unchanged, enveloped in the mucus of the stomach. The saliva of the dog is peculiar in containing a very large quantity of mucin. As previously stated (p. 140), the accumulation of this viscous saliva in the stomach during fasting is calculated so seriously to interfere with absorption, that we, on this account, in nearly all these experiments, injected the various drugs directly into the duodenum.

We would not however have attempted the preceding experiment had we at the moment recollected that the question at issue had already received a satisfactory answer from the previous experiments of KÖLLIKER and MÜLLER, SCOTT, and BENNETT'S Committee. In those experiments the calomel was given by the mouth in the usual way, and the animals had their usual diet. *Every opportunity was therefore afforded for a transformation of the calomel into mercuric chloride*—probably indeed a better opportunity than is afforded in the human subject, for the gastric juice of the dog is—as previously stated, p. 242—more acid than that of man, and yet we find that the action of the calomel, when placed in the stomach of the dog, was just the same as when introduced directly into the duodenum. We have proved that $\frac{1}{20}$ grain corrosive sublimate with 1 grain of calomel when placed in the duodenum (Experiment 78D) can powerfully stimulate the liver of the dog, but we find no reason for entertaining the idea that the amount of mercuric chloride produced by the gastric juice from 5 grains of calomel has any appreciable effect on the liver, for in one of the experiments for BENNETT'S Committee the amount of calomel placed in the stomach was 10 grains, and it occasioned no increased secretion of bile.*

But it may be said, Although these facts render it impossible to entertain the idea that the action of calomel is due to the mercuric chloride produced from it by the gastric juice, is it not possible that the entire absence of the bile from the intestine in the case of the experiments of BENNETT'S Committee interfered with the absorption of the drug, so that while it excited the intestinal glands with which it came directly in contact, it failed to excite the liver because it could not reach it? This objection cannot be entertained—(1) Because Experiments 76 and 76A of the present series prove that when calomel mixed with bile is placed in the duodenum it does not stimulate the liver. (2) In the experiments of BENNETT'S Committee, although the calomel could not possibly encounter bile in the alimentary canal, *a part of it must have been absorbed,* because when given in small doses, frequently repeated, the animal speedily lost its appetite and became extremely unwell, although the doses were too small to produce purgative action.

The conclusion is inevitable, that while corrosive sublimate does—calomel does not—stimulate the liver of the dog, and that when calomel is placed in the stomach of the dog, there is—if the dose be sufficient—the characteristic action on the intestinal glands, but no excitement of the liver. There is therefore no evidence that a purgative dose of calomel, when acted on by the gastric juice, gives rise to mercuric chloride sufficient to exert any appreciable effect on the liver.

Seeing that in these observations we have submitted to direct experiment on the liver of the dog, every substance that has any reputation as a cholagogue in the case of man, and seeing that we have found that, with the exception of calomel, they all increase the biliary *secretion* in the dog, it appears to us that the remarkable harmony between the vast majority of our results and those of clinical experience, entitles us to maintain that our experiments with calomel are not to be set aside by the clinical observer, merely because he is of the opinion that calomel in some way or other increases the discharge of bile in man. There has been on the part of one or two physicians—who in their lamentable ignorance and narrow-mindedness imagine that physiological pharmacology studied on a dog cannot help them to know the action of a drug on man—a tendency to altogether set aside the results of previous experiments with calomel, because they do not harmonise with their previously entertained opinions. These physicians appear to imagine that they can end the discussion by simply saying "the liver of a dog is not that of a man." That truism cannot be disputed, and

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* The dose of calomel was 10 grains given on three successive days. On the first it produced "slight" and on the other two days "decided" purgation, but on all the days the fluid and the solid bile was diminished.

we are perfectly willing to admit that it is possible that the human liver may be more or less susceptible than the liver of the dog to the influence of various substances, but we maintain that up to this time there *is really no proven discord* between our results and those arrived at by observations on man.

All our experiments have had reference to the secretion and not the expulsion of bile. For the purpose of arriving at *definite* knowledge, we intentionally—in the manner described at the outset of these experiments—threw out of action the *bile-expelling* mechanism, in order that we might have to deal with the *bile-secreting* apparatus only. *We do not profess to have ascertained anything regarding the action of any drug on the bile-expelling mechanism.*

The clinical observer has supplied most valuable information regarding the power of various substances to increase the amount of bile in the dejections. He observes dejections of a clay colour, he gives five grains of calomel, and further observes that in some cases the dejections thereafter assume their natural appearance. He cannot be certain of the manner in which this result is brought about. For anything he knows, it might be occasioned (1) by stimulation of the hepatic secreting apparatus; or (2) by stimulation of the muscular fibres of the gall-bladder and larger bile-ducts—to wit—the bile-expelling apparatus; or (3) by removing a catarrhal or congested state of the orifice of the common bile-duct, or of the general extent of the larger bile-ducts; or (4) by removing from the intestine substances which had been passing therefrom into the portal vein and depressing the action of the hepatic cells; or (5) by stimulating the intestinal glands, and thus producing drainage of the portal system, whereby the "loaded" liver might possibly be relieved. Yet notwithstanding the inability of clinical observers to unravel this complicated web, and supply us with any definite statement, one of them* has felt inclined to think the results arrived at by BENNETT's Committee of no value, because they proved by direct experiment that calomel does not in the dog stimulate the hepatic *secreting apparatus.*

Seeing that calomel stimulates the intestinal glands in the dog as in man; seeing that mercury produces salivation, ulceration of gums, and other characteristic phenomena in the dog as in man, the obvious inference is that the reputed cholagogue action of calomel in the human subject is probably not owing to stimulation of the bile-secreting apparatus. And why should we, in the face of our experiments, believe the opposite until the clinical observer substitutes—for *vague conjecture*—definite proof of that opposite, by experimenting in a case of biliary fistula in the human subject, when it happens that no bile enters the intestine, and where the amount secreted may be measured by collecting it as it flows from the fistula.

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* *Vide* Dr MOXON, "Hunterian Oration," 1877, "Medical Press and Circular," March 1877.

Our experiments therefore *suggest* that the cholagogue action of calomel in the human subject is to be sought for, not in any supposed power of stimulating the bile-secreting mechanism, but in some one or more of the last *four* modes of action above indicated. Calomel undoubtedly excites the intestinal glands, and for anything we know there may be something peculiar in the nature of its action thereon. For anything we know, it may also have some special influence on the mucous glands and mucous membrane generally of the larger bile-ducts, whereby a catarrhal condition of these ducts may be relieved and the pent-up bile thus permitted to escape. There is evidently still abundant room for conjecture, but our experiments plainly narrow its range, and thus contribute to the attainment of definite knowledge. The practical physician would, however, do well to observe our discovery, that when a small dose of corrosive sublimate is combined with calomel, stimulation of the liver, as well as of the intestinal glands, is the result. He may probably find it of advantage to apply this combination in the case of man.

SUMMARY OF RESULTS.

1. In a curarised dog that has fasted eighteen hours, the secretion of bile is tolerably uniform during the first four or five hours after the commencement of the experiment, but falls slightly as a longer period elapses. Its composition remains constant.

2. Croton oil is a hepatic stimulant of very feeble power. The high place assigned to it by RÖHRIG was probably the result of his imperfect method of experiment.

3. Podophyllin is a very powerful stimulant of the liver. During the increased secretion of bile, the percentage amount of the special bile-solids is diminished. If the dose be too large, the secretion of bile is not increased. It is a powerful intestinal irritant.

4. Aloes in very large doses is a powerful hepatic stimulant. It renders the bile more watery, but at the same time increases the secretion of biliary matter by the liver.

5. Rhubarb is a certain, though not a powerful, hepatic stimulant. The bile secreted under its influence has the normal composition.

6. Senna is a hepatic stimulant of very feeble power. It renders the bile more watery.

7. Colchicum in very large doses is a powerful stimulant of the liver and intestine. It renders the bile more watery, but increases the secretion of biliary matter proper.

8. Magnesium sulphate stimulates the intestinal glands, but not the liver.

9. Castor oil stimulates the intestinal glands, but not the liver.

10. Gamboge stimulates the intestinal glands, but not the liver.

11. Ammonium chloride stimulates the intestinal glands, but not the liver.

12. Scammony is a powerful intestinal but feeble hepatic stimulant.

13. Euonymin is a powerful hepatic but a feeble intestinal stimulant.

14. Iridin is a powerful hepatic stimulant. It also stimulates the intestine, but not so powerfully as podophyllin.

15. Leptandria is a hepatic stimulant of moderate power. It is a feeble intestinal stimulant.

16. Sanguinarin is a powerful hepatic but a feeble intestinal stimulant.

17. Ipecacuan is a powerful hepatic stimulant. It increases slightly the secretion of intestinal mucus; but has no other apparent stimulant effect on the intestine. The bile secreted under the influence of ipecacuan has the normal composition.

18 Colocynth is, in large doses, a powerful hepatic as well as intestinal stimulant. It renders the bile more watery, but increases the secretion of biliary matter.

19. Jalap is a moderately powerful hepatic, and a powerful intestinal stimulant.

20. Taraxacum is a very feeble stimulant of the liver.

21. Dilute nitrohydrochloric acid is a hepatic stimulant of considerable power.

23. Sodium chloride is a very feeble hepatic stimulant.

23. Rochelle salt is a feeble hepatic, but a powerful intestinal stimulant.

24. Sodium phosphate is a powerful stimulant of the liver and a moderately powerful stimulant of the intestine.

25. Sodium sulphate is a moderately powerful stimulant of the liver and a powerful stimulant of the intestine.

26. Potassium sulphate is a hepatic and intestinal stimulant of considerable power. Its action on the liver is, however, uncertain, probably owing to its sparing solubility.

27. Sodium bicarbonate has scarcely any appreciable effect as a stimulant of the liver, even when given in very large doses.

28. Potassium bicarbonate does not excite the liver unless it be given in very large doses.

29. Potassium iodide has no notable effect on the biliary secretion.

30. Calabar bean stimulates the liver, but not powerfully, unless it be given in very large doses.

31. Atropia sulphate antagonises the effect of Calabar bean on the liver, and thereby reduces the hypersecretion of bile produced by that substance. It does not, however, arrest the secretion of bile, and, when given alone, does not notably affect it.

32. Menispermin does not stimulate the liver. It slightly stimulates the intestinal glands.

33. Baptisin is a hepatic and also an intestinal stimulant of considerable power.

34. Phytolaccin is a powerful hepatic stimulant. It also slightly stimulates the intestinal glands.

35. Hydrastin is a moderately powerful stimulant of the liver and a feeble stimulant of the intestine.

36. Juglandin is a moderately powerful hepatic and a mild intestinal stimulant.

37. Sodium benzoate is a powerful hepatic stimulant. It is not an intestinal stimulant.

38. Ammonium benzoate stimulates the liver, but not quite so powerfully as the sodium salt of benzoic acid. It does not stimulate the intestinal glands.

39. Benzoic acid stimulates the liver, but, owing to its insolubility, its action is less rapid and much less powerful than that of its alkaline salts.

40. Sodium salicylate is a very powerful stimulant of the liver, but a very slight stimulant of the intestinal glands.

41. Ammonium phosphate is a powerful stimulant of the liver. It does not stimulate the intestinal glands.

42. Tannic acid does not affect the secretion of bile.

43. Acetate of lead, in large doses, somewhat lessens the secretion of bile, probably by a direct action on the liver.

44. Jaborandi is a very feeble hepatic stimulant.

45. Sulphate of manganese does not excite the liver, but it is a powerful stimulant of the intestine.

46. Morphia has no appreciable effect on the secretion of bile, and does not prevent the stimulating effect of such a substance as sodium salicylate.

47. Hyoscyamus does not affect the biliary secretion to any noteworthy extent, and does not interfere with the stimulating effect of sodium salicylate.

48. Pure diluted alcohol does not affect the biliary secretion.

49. Calomel stimulates the intestinal glands, but not the liver.

50. Mercuric chloride (corrosive sublimate) is a powerful hepatic, but a feeble intestinal stimulant. When mercuric chloride and calomel are administered together, both the liver and the intestinal glands are stimulated.

51. The injection of 100 cc. (1543 grains) of water into the duodenum gives rise to only a trifling increase of the bile-secretion (Experiment 7).

52. The injection of 3 cc. (46·2 grains) bile into duodenum does not affect the bile-secretion (Experiments 20, 21); 6 cc. (92·4 grains) increase the secretion slightly (Experiment 10).

53. Purgation produced by purely intestinal stimulants, such as magnesium sulphate, gamboge, and castor oil, diminishes the secretion of bile.

54. When a substance—*e.g.*, podophyllin—which powerfully stimulates the intestine as well as the liver is given in too large a dose, the bile-secretion may never be increased (Experiment 9), and though it should be increased in the first instance, it is soon diminished as the excitement of the intestinal mucous membrane extends downwards and implicates a larger and larger number of its glands (Experiment 10).

All the above conclusions are based on experiments performed on the dog, and have no reference to any observations made on the human subject.

Although the hourly coefficients of secretion per kilogramme of body-weight before and after the administration of the principal hepatic stimulants have been already given in detail, it will facilitate a comparison of the effects of the different substances if the results be thrown together as in Table XXXV. As already explained, the coefficients of bile-secretion under the influence of hepatic stimulants cannot be regarded as an absolute index of the relative powers of the stimulants, even in the case of the dog, because, in some instances —*e.g.*, those of aloes, podophyllin, colchicum, and physostigma—the doses were excessive. It would be unfair to compare the effects of such doses with those of moderate doses of other substances. And, as also has been previously stated, young dogs secrete, in proportion to their size, more bile than old dogs; therefore, a higher coefficient is the rule in their case. We have, as far as possible, taken these points into consideration, and the summary of results, above given, contains the conclusions at which we have arrived.

TABLE XXXV.

TABLE XXXV.

Experiment.	Substance Given.			Secretion of Bile per Kilogramme of Body-weight per hour.	
	Name.	Total Dose in Grains.	Grains per Kilogramme of Body-weight.	Before.	After.
				cc.	cc.
1	Normal secretion of bile during the influence of small doses of curara,	...	...	0·35	
2	„ „ „	...	...	0·25	
3	„ „ „	...	...	0·15	
8	Podophyllin,	6, without bile	0·9	0·04	0·47
10	Podophyllin,	4, with bile	0·23	0·52	1·01
11	Aloes,	60, without bile	6·9	0·34	0·69
12	Aloes,	60, „	12·0	0·26	0·93
13	Rhubarb,	68, „	3·06	0·17	0·32
16	Colchicum,	60, „	2·5	0·13	0·45
17	Colchicum,	60, „	2·5	0·10	0·20
28	Euonymin,	5, with bile	0·26	0·25	0·47
27	Euonymin,	5, „	0·21	0·07	0·46
33	Sanguinarin,	1, „	0·05	0·12	0·30
34	Sanguinarin,	3, „	0·11	0·16	0·40
29	Iridin,	5, „	0·22	0·22	0·53
30	Iridin,	5, „	0·92	0·16	0·63
32	Leptandria,	18, „	1·10	0·08	0·31
31	Leptandria,	18, „	0·88	0·19	0·27
36	Ipecacuan,	60, „	2·2	0·24	0·55
37	Ipecacuan,	3, „	0·49	0·18	0·38
39	Colocynth,	14, „	0·53	0·29	0·45
40	Colocynth,	7, „	0·4	0·16	0·27
41	Jalap,	30, „	1·2	0·16	0·29
42	Jalap,	40, „	3·2	0·17	0·35
44A	Dilute Nitro-hydrochloric Acid,	36·4, without bile	2·0	0·11	0·39
46A	Rochelle Salt,	463, with bile	37·2	0·23	0·33
47	Sodium Phosphate,	201, without bile	7·4	0·27	0·44
48	Sodium Sulphate,	120, „	6·1	0·10	0·25
48A	Sodium Sulphate,	508, with bile	32·3	0·25	0·38
49B	Potassium Sulphate,	232, without bile	10·7	0·32	0·47
53	Extract of Physostigma,	2, with bile	0·0074	0·09	0·36
53A	Extract of Physostigma,	2, „	0·0147	0·13	0·75
55	Baptisin,	7, „	0·303	0·23	0·39
57	Baptisin,	7, „	0·374	0·12	0·29
58	Phytolaccin,	2, „	0·064	0·144	0·29
59	Phytolaccin,	2, „	0·104	0·338	0·47
60	Hydrastin,	2, „	0·077	0·23	0·38
61	Hydrastin,	2, „	0·147	0·09	0·32
62	Juglandin,	5, „	0·236	0·10	0·28
		10, „	0·472	0·10	0·32
63	Sodium Benzoate,	20, without bile	1·320	0·22	0·64
64	Ammonium Benzoate,	20, „	0·737	0·24	0·54
73	Sodium Salicylate,	20, „	1·000	0·17	0·56
54	Sodium Salicylate,	25, „	1·550	0·26	0·66
65	Sodium Salicylate,	20, „	2·150	0·32	0·89
78A	Mercuric Chloride,	$\frac{1}{8}$, with bile	0·0077	0·17	0·47
78B	Mercuric Chloride,	$\frac{1}{8}$, „	0·0071	0·20	0·55
78C	HgCl^2, HgCl,	$\frac{1}{20}$, „ 1, „	0·005 0·101	0·48	0·72
78D	HgCl^2, HgCl,	$\frac{1}{20}$, „ 1, „	0·0027 0·054	0·22	0·85

MODE OF ACTION OF HEPATIC STIMULANTS.

Although we have definitely proved that a large number of substances stimulate the liver to secrete more bile, we do not profess to have absolutely shown in what manner they do this. It may be asked—

1. Do they excite the mucous membrane of the duodenum or other part of the small intestine, and thereby induce reflex excitement of the liver? One would be readily disposed to entertain this idea from the fact that stimulation of the oral mucous membrane so readily induces secretion in the salivary glands; yet we are obliged to reject the idea that this likewise holds true of the liver, because such substances as gamboge and magnesium sulphate powerfully irritate the intestinal mucous membrane, while they do not in the least increase the secretion of bile. On the other hand, such substances as ipecacuan, sodium benzoate, and ammonium benzoate powerfully excite the liver without inducing any notable excitement of the intestine.

2. Do these substances stimulate the hepatic cells by merely increasing the stream of blood through the liver? Whatever be the state of the hepatic vessels during increase of the biliary secretion, it is quite certain that increased secretion of bile does not necessarily follow dilatation of the intestinal capillaries; the effect of which, if it be not carried to excess, may with reason be supposed to increase the stream of blood through the portal vein, and thence through the liver. But castor-oil greatly dilates the intestinal capillaries, yet the bile-secretion does not rise in the least.

3. We therefore believe that the effect of hepatic stimulants is to be assigned to a direct action of their molecules upon the hepatic cells or their nerves. The effect of physostigma and atropia rather points to an action on the latter—in their instance, at all events—as has been already indicated (p. 210). But we do not think it advisable at present to pursue this difficult subject, which, as far as we can see, is of little importance compared with knowing what does and what does not stimulate the liver.

It is particularly to be observed that all our experiments concern the influence of substances on the *bile-secreting* mechanism. The nature of our method has forbidden any observations on the action of drugs on the *bile-expelling* mechanism. Seeing that the acid chyme, by irritating the duodenal mucous membrane, effects a reflex expulsion of bile, it may be that many substances which stimulate the duodenum have a similar effect. Yet we cannot but think that to bring about an *expulsion* of bile by muscular contraction of the gall-bladder and bile-ducts is, in all probability, a small thing when compared with increasing the secretion of bile. One might expect that such powerful intestinal irritants as magnesium sulphate and gamboge would be likely to bring about a reflex expulsion of bile; yet no one has attributed any cholagogue power to these. But, without attempting to reason out a question that can only be determined by experiment, we would merely add that we leave the investigation of the action of drugs on the *bile-expelling* mechanism to those who care to enter upon such an inquiry. We are satisfied to have shown that every substance supposed to be a cholagogue has, with the exception of calomel (p. 242) and magnesium sulphate (p. 164), the power of exciting the *bile-secreting* mechanism; and, as our estimate of their powers, from an observation of the *bile-secretion* only, so closely agrees with observations on the human subject, where actions on the bile-secreting and on the bile-expelling mechanisms cannot be distinguished from one another, we cannot but infer that surely their actions on the human subject must be chiefly on the bile-secreting mechanism.

The term cholagogue is of necessity a vague one, and is applicable to any substance that increases the biliary flow, whether by augmenting bile-secretion or by exciting contraction in the walls of the bile-passages. We have, therefore, applied the more definite term *hepatic stimulant* to those substances which we have proved to increase the *secretion* of bile.

HEPATIC DEPRESSANTS.

It cannot fail to strike the reader as a remarkable fact, that while, in the long list of drugs whose hepatic effects we have investigated, we have found so many that stimulate the liver, there is only one—acetate of lead (p. 226)—which appears to have a directly depressant effect. We have, however, found several drugs that have an indirectly depressant action; thus, when the intestinal glands are excited to secrete, there is an indirectly depressant effect on the liver, whereby the bile-secretion is lessened. This we have seen to happen when magnesium sulphate, castor-oil, gamboge, and calomel are given, and doubtless other purely intestinal irritants have a similar effect. We invariably observed that, while slight purgation—by a purely intestinal irritant—scarcely, if at all, depressed the secretion of bile, powerful purgation produced a very marked effect. Why is the action of the liver thus depressed? In our experiments, we had to deal with fasting animals, whose intestinal canals contained neither bile nor food. Under such conditions, magnesium sulphate could not depress the bile-secretion by diminishing the absorption of substances that augment the formation of bile. Its depressant effect seems, therefore, attributable either to a drain from the portal blood of bile-forming substances, or to an excessive lowering of the blood-pressure in the liver, as in the system generally, by a large dilatation of intestinal and mesenteric vessels. But when such a purely intestinal stimulant as magnesium sulphate is given to an individual under ordinary circumstances, it doubtless depresses the secretion of bile, not only in the manner just indicated, but also by hurrying out of the intestinal canal substances which would otherwise have been absorbed and would have assisted in the formation of bile. Thus it cannot be doubted that, when the bile is prevented from entering the intestinal canal, less bile is secreted by the liver, and there is ample reason for believing that about $\frac{7}{8}$ths of the sulphur daily secreted by the liver is reabsorbed from the intestinal canal by the portal vessels—in the form of some sulphur-containing substance derived from the decomposition of taurocholic acid—the sulphur-containing acid of the bile. *And it may be that, in abnormal states of the intestinal contents, various deleterious matters may be absorbed, and hamper hepatic action.* Therefore, it is reasonable to suppose that a purely intestinal stimulant, such as magnesium sulphate, although it does not stimulate the liver, may nevertheless in some abnormal conditions exercise an important influence on that organ, by removing deleterious matters from the intestinal canal, and by draining the portal system. We believe, then, that by the discovery of the depressant effect on hepatic action of purely intestinal purgatives, we have furnished the physician with a fact which will not fail to be of service in rational therapeutics.

Concluding Observations.

In the introduction we pointed out what had been ascertained regarding the actions of drugs on the secretion of bile by our predecessors. We showed that, for want of a proper method of experiment, the definite knowledge arrived at was very meagre, and to some extent erroneous; and, if the statements in that introduction be compared with our summary of results, some idea may be formed of the extent of our labour, which we have striven to render as complete and as free from error as possible. We claim that, by means of a novel and precise method of investigation, we have been the first to place the whole subject of the physiological actions of drugs on the bile-secreting function of the liver upon a sound footing, and thus to lay a real foundation for the rational —that is, scientific—treatment of many diseased conditions of this important organ; and it is gratifying to know that, in consequence of this research, many physicians have been led to use new remedies to which we have specially directed attention. We have indeed occasioned, by our experiments, a considerable amount of pain to a number of dogs; but, considering that our discoveries are calculated to relieve much suffering, not only of men, but also of dogs, for all time to come, we believe that we have spared infinitely more suffering in the future than we have occasioned in the present.

In conclusion, I have to tender my warm thanks to my former pupils, M.

VIGNAL and WILLIAM J. DODDS, M.B., D.Sc., for their valuable assistance in the performance of the experiments, and for their company during the long and weary hours through which they daily extended. I have very cordially to thank the Scientific Grants Committee of the British Medical Association for having voted upwards of £200 from the funds of the Association to defray the very heavy expenses incurred for the materials for the research, and for their energetic and powerful support at a time when the clamour of blind ignorance and silly prejudice seriously menaced and almost arrested the progress of this research. Having personally devoted not less than 1400 hours of severe labour to the accomplishment of this work, and having (as, of course, every medical man thinks himself bound to do for the alleviation of suffering) communicated to all every fact calculated eventually to cure affections so common as those of the liver, it is, to say the least, ungrateful, that a certain section of the public should have rewarded our unselfish efforts to cure their hepatic derangements by a flood of abuse; because, like most of our medical brethren, we believe that to be penny-wise and pound-foolish as regards pain is a policy as short-sighted, as narrow-minded, and as reprehensible here as elsewhere. Though profuse with their ingratitude, I doubt not that one and all of them will be very ready and eager to profit by the results of our labour; for I suspect that most of them are scarcely willing to refuse all medical aid, and to thus push their logic to its practical issue. Desiring, as I think most of them do, to continue in receipt of all the medical assistance they can obtain, it may possibly satisfy their conscientious scruples to vainly attempt to make it appear that *nothing worth knowing* in medicine has been learned from experiments on animals. It is not difficult, by misrepresentation and by a multiplicity of words, to deceive a public ignorant of the machinery of life and of the processes by which its movements are studied and remedies found for its disorders; but they cannot thus deceive any moderately well informed and right-minded medical practitioner. The discourtesy, misrepresentation, and injustice that we have suffered at the hands of those who should have acted otherwise, has not, however, induced us to prove false to the interests of suffering humanity. We are conscious of having faithfully done our utmost to advance the scientific treatment of diseases of the liver, and while steadily pursuing this great object we have been most careful to avoid the infliction of all pain that was not absolutely necessary.

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INDEX.

ERRATUM.

Page 259, line 7 from the top of page, *for* "Magnesium sulphate (p. **164**)," *read* "Sulphate of manganese (p. 230)."

VI.—*On Some New Bases of the Leucoline Series.* PART II. By G. CARR ROBINSON, F.R.S.E., and W. L. GOODWIN.

(Read 19th May 1879.)

In a former paper read before the Society, and published in the Society's "Transactions,"* on "Some New Bases of the $C_nH_{2n-11}N$ series," obtained from the "vitriol-tar," from the distillation of shale, evidence was given of the isolation of three bases of this series, in addition to the Leucoline, Iridoline, and Cryptidine of G. WILLIAMS.

In this paper it was pointed out that the three new bases, $C_{12}H_{13}N$, $C_{13}H_{15}N$, and $C_{14}H_{17}N$, were obtained by the fractional distillation of the mixed bases after treating alternately with caustic soda and sulphuric acid. In the first experiment, in which a comparatively small quantity of material was used, and where fractional distillation was continued to twenty-five times, the presence of these bases was indicated by the analysis of their chloroplatinates, in those fractions which from theoretic considerations might be expected to contain them; *e.g.*, Cryptidine, the last of G. WILLIAMS' series, was found by him to have a boiling-point of 274° C., whilst Iridoline and Leucoline had boiling-points of 256° C. and 238° C. respectively, showing a difference of 18° C. for each addition of CH_2 to the molecule. The next member in ascending the series would be expected to lie in fraction 290°–295° C., its theoretic boiling-point being 292°C.; accordingly, analysis of chloroplatinate from fraction 290°–295°C. showed 26·12 per cent. of platinum, corresponding with percentage of platinum required for chloroplatinate of new base $C_{12}H_{13}N$.†

The quantity of bases in this first experiment being much too small to allow of any satisfactory examination of their fractions, a second and larger quantity was, after going through the same processes of purification, submitted to fractional distillation, and the corresponding fractions 290°–295°, 310°–315°, &c., examined. Here a curious anomaly in the boiling-points was observed: the three bases $C_{12}H_{13}N$, $C_{13}H_{15}N$, and $C_{14}H_{17}N$, were obtained; but each was found in the fraction one step lower than was anticipated, *i.e,* in fractions 270°–275°, 290°–295°, 310°–315° respectively, instead of in fractions 290°–295°, 310°–315°, and 325°–330°. The explanation offered was that in the first experiment twenty-

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* "Transactions Royal Society, Edinburgh," vol. xxviii. part ii. "On Some New Bases of the Leucoline Series."

† Trans. Royal Soc. Edin., vol. xxviii. pt. ii. page 563.

five complete fractionations had been made, whilst in the second experiment only sixteen fractionations were made; and it was the desire of more completely isolating the higher members of this series, and, if possible, ascertaining their true position in the series by longer continued fractional distillation, that has given rise to the present paper.

In order to carry out this investigation, we were again kindly supplied by Messrs GELLATLY and THOMSON with a quantity of crude bases, about one gallon; these were purified as follows:—the crude bases, being a mixture chiefly of bases, tarry matter, and paraffin, were digested for several hours with dilute sulphuric acid, the insoluble portion separated by filtration, and the acid liquor neutralised with caustic soda; the so-separated bases were again dissolved in dilute sulphuric acid, again treated with caustic soda, and this process repeated other three times, when the mixture of bases was considered sufficiently pure to be distilled. After eight distillations, a large quantity of black tarry matter being left in the still from each operation, fractional distillation was commenced.

Fractional Distillation of the Mixed Bases.

After twelve complete fractionations, fractions ranging from 250°C. to 390° C. about 5 grms. of fraction 260°–270° C. was dissolved in strong nitric acid, the solution evaporated to dryness on water-bath, the residue treated with water, and to the aqueous solution, cooled in freezing mixture, platinum chloride added. The precipitated platinum salt was washed with ice-cold water, then with a mixture of alcohol and ether, dried over sulphuric acid and finally at 100° C.

Analysis gave—

I. 25·52 per cent. platinum.
II. 25·55 ,, ,,

Fractional distillation was then continued to twenty times and platinum salts prepared from fractions 270°–275° and from fraction 290°–295° in same manner as from 260°–270°.

Analysis of platinum salt from fraction 270°–275°—

I. 24·74 per cent. platinum.
II. 24·63 ,, ,,

This fraction might be expected to contain Cryptidine, $C_{11}H_{11}N$, and as the chloroplatinate of that base, $2C_{11}H_{11}NHCl, PtCl_4$, requires 27·13 per cent. platinum, the small percentage of platinum was quite inexplicable, except on the assumption that during the process of evaporating with nitric acid a nitro-substitution compound had been formed. Assuming that one atom of hydrogen were replaced by (NO_2), we should have from cryptidine the body $2C_{11}H_{10}(NO_2)NHCl, PtCl_4$, which requires 24·14 per cent. platinum.

Similarly, the chloroplatinate from fraction 290°–295° showed 23·37 per cent. platinum, this being far too low for platinum salt of base $C_{12}H_{13}N$, that salt requiring 26·12 per cent., the presence of a nitro-compound was inferred from the fact that the percentage of platinum obtained agreed closely with the calculated quantity for the body having the formula $2C_{12}H_{12}(NO_2)NHCl, PtCl_4$, this body requiring 23·34 per cent. platinum, found 23·37 per cent.

In order to more completely separate the bases five more fractional distillations were made, this making twenty-five fractionations in all, and involving some six hundred distillations.

Again a platinum salt was prepared from fraction 290°–295° by dissolving the base in nitric acid as on former occasions, this yielded 23·54 and 23·52 per cent. platinum, agreeing with the salt made after twenty fractionations, thus showing that the last five fractional distillations had not effected any further separation, and further strengthening the supposition that the bodies obtained by the action of nitric acid were nitro-compounds. The further examination of these bodies was not proceeded with at this stage, as we considered it more advisable to attempt the identification of the bases in the first instance without the use of nitric acid, employing only hydrochloric acid as the solvent.

The method adopted for obtaining the chloroplatinates was therefore as follows:—About 3–5 grms. of the fraction under examination was dissolved in 20–30 cc. of dilute hydrochloric acid and the solution boiled, when a small quantity of a black tarry substance separated; this was filtered off, and the clear solution, diluted with five to six times its volume of water, was cooled in freezing mixture. To the diluted solution was added platinum chloride, the chloroplatinate precipitated as a fine granular yellow mass was collected on a filter washed several times with ice-cold water, then with a mixture of alcohol and ether, dried over sulphuric acid, and finally dried at 100° C.

Examination of Fraction 270°–275°.

Chloroplatinate prepared as above,

0·2805 grms. gave
0·0765 „ platinum = 27·27 per cent.

This agrees with percentage of platinum demanded by chloroplatinate of cryptidine, bg. pt. 274° C., the formula for which $2C_{11}H_{11}NHCl, PtCl_4$, requires 27·13 per cent., this being sufficient evidence of the presence of cryptidine, and also indicating that this time the increased number of fractional distillations to which the bases had been subjected had brought them up to their hypothetical boiling-points, the carbon and hydrogen in this salt was not determined.

Examination of Fraction 290°–295°.

Analysis of chloroplatinate—

I. 0·198 grms. salt gave
0·051 „ platinum = 25·76 per cent. platinum.

II. 0·164 „ salt gave
0·04225 „ platinum = 25·77 „ „

III. 0·31175 „ salt gave
0·082 „ platinum = 26·30 „ „

IV. 0·2895 „ salt gave
0·40085 „ CO_2 = 37·76 „ carbon.
0·122 „ H_2O = 4·49 „ hydrogen.

V. 0·52525 „ salt gave
0·72675 „ CO_2 = 37·70 „ carbon
0·208 „ H_2O = 4·37 „ hydrogen.

VI. 0·44725 „ salt gave
0·62275 „ CO_2 = 37·75 „ carbon.
0·17375 „ H_2O = 4·35 „ hydrogen.

These results agree with the percentage composition of chloroplatinate of first new base $C_{12}H_{13}N$, the formula for which $2C_{12}H_{13}NHCl$, $PtCl_4$, requires—

		Found.					
	Calculated.	I.	II.	III.	IV.	V.	VI.
Carbon, . .	38·19	37·76	37·70	37·75	...	...	...
Hydrogen, .	3·72	4·49	4·37	4·31	...	...	...
Platinum, .	26·12	...	...	...	25·76	25·77	26·30

Examination of Fraction 305°–310°.

Analysis of chloroplatinate—

I. 0·216 grms. salt gave
0·054 „ platinum = 25·00 per cent. platinum.

II. 0·2165 „ salt gave
0·054 „ platinum = 24·94 „ „

Examination of Fraction 310°-315°.

Analysis of chloroplatinate—

I. 0·277 grms. salt gave
0·07 „ platinum = 25·27 per cent. platinum.

II. 0·301 „ salt gave
0·076 „ platinum = 25·25 „ ,

III. 0·458 grms. salt gave
0·1145 „ platinum = 25·00 per cent. platinum.

IV. 0·54275 „ salt gave
0·77875 „ CO_2 = 39·47 „ carbon.
0·233 „ H_2O = 4·79 „ hydrogen.

V. 0·42525 „ salt gave
0·62 „ CO_2 = 39·95 „ carbon.
0·18 „ H_2O = 4·70 „ hydrogen.

Both these fractions, 305°–310° and 310°–315°, therefore consist of the second new base, $C_{13}H_{15}N$, the theoretical boiling-point of which is 310° C., the formula of its chloroplatinate $2C_{13}H_{15}NHCl, PtCl_4$, requiring—

		Found.				
	Calculated.	I.	II.	III.	IV.	V.
Carbon,	39·89	39·47	39·95	...	...	...
Hydrogen,	4·09	4·79	4·70	...	...	...
Platinum,	25·19	...	...	25·27	25·25	25·00

Examination of Fraction 325°–330°.

Analysis of chloroplatinate—

I. 0·287 grms. salt gave
0·0695 „ platinum = 24·21 per cent. platinum.

II. 0·183 „ salt gave
0·044 „ platinum = 24·03 „ „

III. 0·271 „ salt gave
0·066 „ platinum = 24·35 „ „

IV. 0·388 „ salt gave
0·5885 „ CO_2 = 41·36 „ carbon.
0·16 „ H_2O = 4·56 „ hydrogen.

V. 0·2965 „ salt gave
0·4515 „ CO_2 = 41·51 „ carbon.
0·1205 „ H_2O = 4·52 „ hydrogen.

These results show this fraction to consist of the third new base, $C_{14}H_{17}N$, the theoretical boiling-point of which is 328° C. The formula of its chloroplatinate $2C_{14}H_{17}NHCl, PtCl_4$, requiring—

		Found.				
	Calculated.	I.	II.	III.	IV.	V.
Carbon,	41·48	41·36	41·51	...	...	...
Hydrogen,	4·44	4·56	4·52	...	...	...
Platinum,	24·37	...	...	24·21	24·03	24·35

Examination of Fraction 345°–350°.

Analysis of chloroplatinate—

I. 0·3695 grms. salt gave
0·8725 „ platinum = 23·61 per cent. platinum.

II. 0·23025 „ salt gave
0·055 „ platinum = 23·84 „ „

III. 0·2825 „ salt gave
0·4475 „ CO_2 = 43·18 „ carbon.
0·1135 „ H_2O = 4·40 „ hydrogen.

IV. 0·5685 „ salt gave
0·896 „ CO_2 = 42·99 „ carbon.
0·2295 „ H_2O = 4·48 „ hydrogen.

These analyses show the salt to be the chloroplatinate of the fourth new base, $C_{15}H_{19}N$, theoretical boiling-point 346° C. Its chloroplatinate has the formula $2C_{15}H_{19}NHCl, PtCl_4$, and composition—

	Calculated.	Found.			
		I.	II.	III.	IV.
Carbon, ...	42·95	42·99	43·18	...	...
Hydrogen, . . .	4·53	4·48	4·40	...	...
Platinum, . . .	23·50	...	...	23·61	23·84

Examination of Fraction 360°–365°.

Analysis of chloroplatinate—

I. 0·2525 grms. salt gave
0·058 „ platinum = 22·96 per cent. platinum.

II. 0·288 „ salt gave
0·066 „ platinum = 22·91 „ „

III. 0·414 „ salt gave
0·667 „ CO_2 = 43·96 „ carbon.
0·186 „ H_2O = 4·97 „ hydrogen.

IV. 0·435 „ salt gave
0·702 „ CO_2 = 44·00 „ carbon.
0·199 „ H_2O = 5·08 „ hydrogen.

These analyses show this salt to be the chloroplatinate of the fifth new base, $C_{16}H_{21}N$, theoretical boiling-point 364° C. Its chloroplatinate has the formula $2C_{16}H_{21}NHCl, PtCl_4$, and composition—

	Calculated.	Found.			
		I.	II.	III.	IV.
Carbon, ...	44·34	43·96	44·00	...	...
Hydrogen, . . .	5·08	4·97	5·08	...	...
Platinum, . . .	22·75	...	...	22·96	22·91

Fractions of higher boiling-points were not examined, one other within the series, viz., 380°–385°, was obtained (which would probably contain the base $C_{17}H_{23}N$) but only in very small quantity and containing paraffin; but from those fractions examined, viz., 290°–295°, 305°–310°, and 310–315°, 325°–330°, 345–350°, and 360°–365°, we have been able, by the analysis of the platinum salts, to separate and identify five new members of the series of Leucoline bases, viz., the base $C_{12}H_{13}N$ from fraction 290°–295°, $C_{13}H_{15}N$ from fractions 305°–310° and 310°–315°, $C_{14}H_{17}N$ from fraction 325°–330°, $C_{15}H_{19}N$ from fraction 345°–350°, and $C_{16}H_{21}N$ from fraction 360°–365°. Taking Leucoline, Iridoline, and Cryptidine with boiling-points 238°, 256°, and 274° respectively, it will be seen that the boiling-points of the five higher members of the series would be 292°, 310°, 328°, 346°, and 364°; we have not been able to ascertain the actual boiling-points of these higher members of the series, but have shown that the fractions, within a range of 5° C., consist practically of such bases; and, as is seen from analyses of chloroplatinate from fractions 305°–310° and 310°–315°, also from other analyses not noted, the same base extends over a considerable range of temperature.

In a former paper on these bases,* wherein the identification of $C_{12}H_{13}N$, $C_{13}H_{15}N$, and $C_{14}C_{17}N$ was recorded, an apparent anomaly in their boiling-points was observed; the base $C_{12}H_{13}N$ being found in fraction 270°–275° instead of in fraction 290°–295°, $C_{13}H_{15}N$ in fraction 290°–295°, instead of fraction 310°–315°, &c., and the explanation was offered that fractional distillation had not been pushed far enough, that were it continued at least twenty-five or thirty times, these three bases would be found in fractions 290°–295°, &c. The present investigation has shown this to be the case, fractional distillation being continued to twenty-five times before the bases were submitted to examination, with the result already stated.

It is necessary to mention that fractional distillation at these very high temperatures was effected by means of the high-range thermometers made by the late Dr Geissler of Bonn; these thermometers are so constructed as to indicate temperatures up to 460° C. All distillations above 300° C. were made in the above manner, distillation being pushed as long as any distillate was produced, the limit to this being found to lie about 390° C., when a thick tarry residue was left in the flask.

When recently distilled these bases are of a pale brown colour; they rapidly darken when exposed to the atmosphere, and even when enclosed in hermetically sealed tubes the same darkening in colour goes on, but more slowly. They thicken and appear to become resinous when kept for some time in an imperfectly closed vessel, and, as the series is ascended, the more rapidly do they become resinous.

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* Trans. Royal Society, Edinburgh, vol. xxviii. part ii. p. 569.

The salts of these bases, if we except the lower members of the series, do not appear to crystallise. As already stated, the chloroplatinates are precipitated in the form of granular yellow masses, which under the microscope appear to consist of tufts of silky crystals, but we have hitherto completely failed to re-crystallise the precipitated chloroplatinate, as was effected by G. WILLIAMS with the platinum salt of cryptidine.

We would suggest, that in order to distinguish these five bases from their isomers of the Chinoline series—Tetrahiroline, &c., they should be termed Tetracoline, Pentacoline, &c., thus WILLIAMS' bases being Leucoline, Iridoline, and Cryptidine, the series will now consist of—

Leucoline, . . .	C_9H_7N	Pentacoline, . .	$C_{13}H_{15}N$
Iridoline, . . .	$C_{10}H_9N$	Hexacoline, . .	$C_{14}H_{17}N$
Cryptidine, . . .	$C_{11}H_{11}N$	Heptacoline, . .	$C_{15}H_{19}N$
Tetracoline, . .	$C_{12}H_{13}N$	Octacoline, . .	$C_{16}H_{21}N$

Action of Nitric Acid on these Bases.

The study of the action of nitric acid on these five bases has not as yet yielded any very promising results. As was stated in an early part of this paper, we were led to believe from the analysis of the platinum salts prepared by evaporating the bases with strong nitric acid, that "nitro-compounds" were formed. At two stages of the fractional distillation—at the twentieth and the twenty-fifth—platinum salts were prepared from fraction 290°–295° by dissolving the base in strong nitric acid, evaporating the solution on water-bath, treating the residue with water, and from this precipitating the platinum salt by addition of platinum chloride; both salts yielded 23·37 per cent. platinum, this corresponding with the calculated percentage of platinum in substance having the formula $2C_{12}H_{11}(NO_2)NHCl, PtCl_4$, but further examination did not bear out this theory, for the same platinum salt yielded on combustion—

	I.	II.
Carbon, . . .	39·42	39·00
Hydrogen, . .	4·5	4·5

whereas the above formula requires only—

Carbon, . . .	34·12 per cent.
Hydrogen, . . .	3·08 „

It is apparent also from these analyses that the chloroplatinate prepared with nitric acid have not the same composition as those prepared with hydrochloric acid.

VII.—*On some New Bases of the Leucoline Series.* Part III.—*The Action of Iodide of Methyl on Tetracoline, Pentacoline, Hexacoline, Heptacoline, and Octacoline.* By G. Carr Robinson, F.R.S.E., and W. L. Goodwin.

(Read 16th June 1879.)

In the first paper read before this Society "On some New Bases of the Leucoline Series," and published in the Society's "Transactions,"* it was stated that amongst other methods proposed for separating the members of the series and identifying the higher bases, was the process of converting the mixed bases into methyl-iodide compounds by digesting them with the iodide at a high temperature, and separating by fractional crystallisation the bodies so produced. It was found, however, that repeated crystallisation of these bodies could not be effected without great risk of their decomposition. This process was, therefore, abandoned in favour of fractional distillation.

Subsequent investigation of these bases by the latter process—that of fractional distillation—yielded five new members of the series, viz. :—Tetracoline, $C_{12}H_{13}N$; Pentacoline, $C_{13}H_{15}N$; Hexacoline, $C_{14}H_{17}N$; Heptacoline, $C_{15}H_{19}N$; and Octacoline, $C_{16}H_{21}N$. These bases, as was shown by the analyses of their platinum salts, being obtained in a state of great purity.

We are now enabled to lay before the Society the results arrived at by the study of the action of methyl-iodide on the pure bases.

This inquiry has shown that these bases combine readily with methyl-iodide, that the bodies so produced can readily be obtained in a state of great purity, and that, owing to this circumstance, they can be examined more easily and expeditiously than the platinum salts of the bases.

With Tetracoline, $C_{12}H_{13}N$, and Pentacoline, $C_{13}H_{15}N$, iodide of methyl unites at ordinary temperatures. On dissolving the base in the iodide and agitating the solution, yellow crystals of the iodide of methyl-tetracoline and of methyl-pentacoline appear in a few minutes. With Hexacoline, $C_{14}H_{17}N$, and the higher members, iodide of methyl only combines when digested for some time with the base at 100° C.

When these bases are digested with iodide of methyl on the water-bath in a flask fitted with an inverted condenser, the methyl compound is quickly thrown down in a fine powdery condition and always of a green colour. By heating the solution of the base in methyl-iodide in sealed tubes, the salt is obtained in well-defined crystals, the yield is larger, and the colour of the salt varies with the different bases ; *e.g.*, the iodide of methyl-tetracoline so obtained

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* "Transactions of Royal Society of Edinburgh," vol. xxviii. part ii.

is pale yellow, that of methyl-pentacoline olive-green, of methyl-octacoline brilliant orange, &c.

These bodies are sparingly soluble in cold, readily in hot, alcohol; the solution exhibiting the fluorescence which is observed in the recently-distilled base itself.

When pure, these iodides of methyl compounds show considerable stability; decomposition, in the case of iodide of methyl-tetracoline, not taking place below 190° C.

Action of Iodide of Methyl on Tetracoline, $C_{12}H_{13}N$.

A portion of fraction 290°–295° C., consisting of the base *tetracoline*, $C_{12}H_{13}N$, was mixed with an excess of iodide of methyl (about 1 vol. base to 3 vols. iodide), and heated in a sealed tube in the water-bath for thirty minutes. On cooling, the semi-solid mass of yellow crystals was thrown on a filter, the excess of methyl-iodide filtered off, and the crystals, after being well washed with cold alcohol, in which they were very sparingly soluble, were dried at 100° C.

Analysis showed these crystals to be the *iodide of methyl-tetracoline*, $C_{12}H_{13}NCH_3I$.

Analysis—

I. 0·1855 grms. crystals dried at 100° C. gave—
0·341 „ CO_2 = 50·13 per cent. carbon.
0·097 „ H_2O = 5·40 „ hydrogen.
II. 0·3745 „ gave—
0·69 „ CO_2 = 50·20 per cent. carbon.
0·189 „ H_2O = 5·60 „ hydrogen.
III. 0·3035 „ gave—
0·226 „ AgI = 40·23 per cent. iodine.

$C_{12}H_{13}NCH_3I$, iodide of methyl-tetracoline, requires—

	Calculated	Found		
		I.	II.	III.
Carbon, .	49·84	50·13	50·20	...
Hydrogen, .	5·11	5·40	5·60	...
Iodine, .	40·58	...	...	40·23

Chloroplatinate of Methyl-tetracoline.

In order to obtain this substance, iodide of methyl-tetracoline prepared from fraction 285°–290° C. was dissolved in boiling alcohol. On cooling, a crop of minute pale-yellow crystals of the iodide was thrown down. The mother-liquor from these was treated with solution of silver nitrate, the iodide of silver filtered off, and the excess of silver thrown down by dilute hydrochloric acid.

The filtered solution of the chloride of methyl-tetracoline was cooled in freezing mixture, and to it was then added platinum chloride, when the platinum salt was precipitated in a fine granular condition, this was washed with ice-cold water, then with alcohol and ether, and dried at 100° C.

Analysis of platinum salt—

I. 0·187 grms. salt gave—
0·0465 „ platinum = 24·87 per cent. platinum.
II. 0·294 „ salt gave—
0·0735 „ platinum = 25·00 per cent. platinum.
III. and IV., a mean of the results of two combustions, gave—
39·75 per cent. carbon.

These analyses show the body to be the *platinum salt of methyl-tetracoline*, the formula of which, $2C_{12}H_{13}NCH_3Cl, PtCl_4$, requires—

		Calculated	Found		
			I.	II.	III.
Carbon,	.	39·89	39·75	...	...
Hydrogen,	.	4·09	mean of two analyses	...	...
Platinum,	.	25·19	...	24·87	25·00

It is apparent that the *chloride of methyl-tetracoline*, $C_{12}H_{13}NCH_3Cl$, is isomeric with the *hydrochlorate of pentacoline*, $C_{13}H_{15}NHCl$.

Owing to the very small quantity of material worked upon, we were unable to isolate the methyl base, the examination of whose properties would not improbably throw very considerable light on the constitution of this series.

Action of Iodide of Methyl on Pentacoline, $C_{13}H_{15}N$.

A portion of fraction 305°–310° C., consisting of the base *pentacoline*, $C_{13}H_{15}N$, was heated in a sealed tube with iodide of methyl in the water-bath, as in the case of tetracoline. The *iodide of methyl-pentacoline* was obtained in olive-green crystals; these, washed with cold alcohol and dried at 100° C., gave on analysis—

I. 0·26125 grms. crystals dried at 100° C. gave—
0·489 „ CO_2 = 51·24 per cent. carbon.
0·134 „ H_2O = 5·69 „ hydrogen.
II. 0·1096 „ gave—
0·2065 „ CO_2 = 51·37 per cent. carbon.
0·055 „ H_2O = 5·5 „ hydrogen.
III. 0·252 „ gave—
0·181 „ AgI = 38·80 per cent. iodine.
IV. 0·315 „ gave—
0·2255 „ AgI = 38·66 per cent. iodine.

These results agree with the formula of *iodide of methyl-pentacoline*, $C_{13}H_{15}NCH_3I$.

	Calculated	Found			
		I.	II.	III.	IV.
Carbon, .	51·37	51·24	51·37	...	...
Hydrogen, .	5·50	5·69	5·50	...	...
Iodine, .	38·84	...	...	38·80	38·66

From fraction 310°–315° C., also consisting of *pentacoline*, the iodide of methyl-pentacoline was prepared. The salt was obtained in olive-green crystals, these, dried at 100° C., gave on analysis—

I. 0·296 grms. gave—
0·213 „ AgI = 38·82 per cent. iodine.
II. 0·248 „ gave—
0·177 „ AgI = 38·57 per cent. iodine.

The formula of the salt $C_{13}H_{15}NCH_3I$, as already shown, requiring 38·84 per cent. iodine.

Action of Iodide of Methyl on Hexacoline, $C_{14}H_{17}N$.

A portion of fraction 325°–330° C., consisting of the base *hexacoline*, $C_{14}H_{17}N$, was heated in a sealed tube with iodide of methyl in the water-bath for thirty minutes. The iodide of methyl-hexacoline was obtained in lemon-yellow crystals; these, washed with cold alcohol and dried at 100° C., gave on analysis—

I. 0·2125 grms. crystals gave—
0·4125 „ CO_2 = 52·96 per cent. carbon.
0·107 „ H_2O = 5·58 „ hydrogen.
II. 0·093 „ gave—
0·0639 „ AgI = 37·12 per cent. iodine.

These results agree with the formula of *iodide of methyl-hexacoline*, $C_{14}H_{17}NCH_3I$.

	Calculated	Found	
		I.	II.
Carbon, . .	52·78	52·96	...
Hydrogen, . .	5·87	5·88	...
Iodine, . .	37·24	...	37·12

Action of Iodide of Methyl on Octacoline, $C_{16}H_{21}N$.

A portion of fraction 355°–360° C., consisting presumably of the base *octacoline,* $C_{13}H_{21}N$, for in a former investigation it was from fraction 360–65° C. that this base was obtained, was heated in a sealed tube with iodide of methyl in the water-bath for thirty minutes. On cooling, the iodide of methyl compound crystallised out in brilliant orange needles. The crystals were collected on a filter, well washed with cold alcohol, and dried at 100° C.

Analysis of orange-coloured crystals dried at 100° C. :—

I. 0·231 grms. gave—
0·464 „ CO_2 = 54·89 per cent. carbon.
0·1116 „ H_2O = 5·36 „ hydrogen.
II. 0·116 „ gave—
0·074 „ AgI = 34·39 per cent. iodine.
III. 0·249 „ gave—
0·1575 „ AgI = 34·18 per cent. iodine.

These analyses show this salt to be the *iodide of methyl-octacoline,* $C_{16}H_{21}NCH_3I$, the formula of which requires—

	Calculated	Found I.	Found II.	Found III.
Carbon, .	55·28	54·89	...	...
Hydrogen, .	6·50	5·36	...	...
Iodine, .	34·41	...	34·39	34·18

The deficiency in the percentage of hydrogen found is inexplicable, but from the carbon and iodine determinations agreeing so closely with the theoretical quantities, it is apparent that these crystals are the iodine of methyl-octacoline. The fraction from which they were prepared, 355°–360°, is, therefore, the same in composition as the one previously examined, 360°–365° C.; bearing out the statement made in a former paper that amongst bodies of such high molecular weights and high boiling-points the same base is found in a state of considerable purity, extended over several fractions. In the present investigation *tetracoline* has been found in fractions 285°–290° and 290°–295° C., its theoretical boiling-point being 292° C.; likewise *pentacoline* was found in fractions 305°–310° and 310°–315°, its theoretical boiling-point being 310° C.; and lastly, *octacoline* was found in fractions 355°–360° and 360°–365°, its theoretical boiling-point being 364° C.

Action of strong Nitric Acid on these Bases.

When these bases are dissolved in dilute hydrochloric acid, and the solution is boiled with the addition of a few drops of dilute nitric acid, the only apparent effect the latter has is that of a purifying nature, by causing the separation of a small quantity of a black tarry substance. This was observed by GREVILLE WILLIAMS, and was mentioned by him as a means of purifying Cryptidine.*

When the bases are treated with strong nitric acid an intensely purple solution is obtained, and if this solution be evaporated on the water-bath a sticky resinous mass remains. The resinous mass, when digested with water, is dissolved only to a very small extent, yielding a solution which, when treated with dilute hydrochloric acid and platinum chloride, gives a platinum salt showing percentage of platinum agreeing with that required† for a nitro-substitution body. Further examination into that portion of the resinous mass insoluble in water has led us to regard it as the nitrate of the base. A quantity of tetracoline was dissolved in strong nitric acid, and the solution evaporated on the water-bath; the resinous mass was digested with three successive quantities of water, and the insoluble portion dried at 100° C. A brittle amber-coloured resinous substance, readily soluble in alcohol, was obtained.

Analysis gave the following:—

I. 0·226 grms. gave—
0·509 „ CO_2 = 61·41 per cent. carbon.
0·12 „ H_2O = 5·89 „ hydrogen.
II. 0·2105 „ gave—
0·4755 „ CO_2 = 61·60 per cent. carbon.
0·112 „ H_2O = 5·89 „ hydrogen.

These analyses would show the resin to be the *nitrate of tetracoline*, $C_{12}H_{13}N.HNO_3$, which requires—

	Calculated	Found	
		I.	II.
Carbon, . .	61·54	61·41	61·60
Hydrogen, . .	5·98	5·89	5·89
Nitrogen, . .	11·96	...	...

In the first paper on this research‡ the extreme difficulty experienced in

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* "Transactions R.S.E.," vol. xxi. p. 401.

† "Some New Bases of the Leucoline Series," part ii., Transactions R.S.E., vol. xxix. part i.

‡ "Transactions R.S.E.," vol. xxviii. part ii., "On some New Bases of the Leucoline Series."

obtaining crystalline salts from the mixed bases was noted; "the double chlorides of platinum, gold, cadmium, mercury, lead, and zinc were tried, but without success, only resinous sticky masses being obtained." With the pure and isolated bases we have since been able to get crystalline salts. Crystals, nearly one-eighth of an inch in length, of the double *chloride of mercury and tetracoline,* were prepared by adding solution of mercuric chloride to solution of chloride of tetracoline, and dissolving in hot water the sticky globules that are produced, on cooling white transparent crystals of the double chloride appear.

When solution of chloride of cadmium is added to solution of chloride of tetracoline a white precipitate of the double chloride comes down. If now the contents of the tube be agitated, the precipitate settles on the sides in sticky globules of a dark purple colour, which allow of the liquid to be poured off and the globules washed. After some days tufts of minute silky crystals shoot from and cover the dark globules. Examination of these showed them to be the double *chloride of cadmium and tetracoline.*

Pentacoline and the higher bases do not appear to form crystalline salts with these metals.

VIII.—*On the Transmission of Sound by Loose Electrical Contact.*

By JAMES BLYTH, M.A.

(Read 27th July 1879).

In a paper published in the Transactions of this Society for Session 1877–78, I described an experiment which showed, that if a moderately strong current, such as that from four or five BUNSEN cells, be led through two jam-pots filled with fragments of carbon, and if any sound be uttered strongly in the one jam-pot it will be reproduced distinctly, although faintly, in the other. In this experiment it has been found that the fragments of carbon may be replaced by any kind of loose contact, such as microphones, or a handful of screw-nails put into each jam-pot, or vibrating springs beating against metallic stops, or nails laid across each other in log-hut fashion, and that in each case an effect similar in kind, although it may be differing greatly in degree, is produced. Hence it may be almost laid down as a general experimental result, that if an electric circuit conveying a tolerably strong current contain two places of loose contact, A and B, and if any sound be produced loud enough at A a similar sound will be heard proceeding from B.

To all appearance this phenomenon can only arise from the altered resistance produced at A by the sound waves, and it becomes a problem to explain how this altered resistance at A so affects the materials in contact at B as to make them give forth waves which convey a similar sound to the ear. No satisfactory solution of this problem has as yet been given, and it was in hopes of getting some information on the subject that I made the following experiments.

Experiment 1.—Four strong BUNSEN cells were included in the circuit, and the loose contacts A and B placed in different rooms, so that the sound uttered at A could not be directly heard at B. (Throughout we shall understand by A the sending, and B the receiving station.) In order to make the alteration of resistance at A as great as possible, an actual make-and-break was there inserted. A toothed wheel driven round against a spring or any one of the ordinary loud-sounding automatic kinds would do; but what served my purpose best in this experiment was made in the following way:—One of the terminal wires of the circuit was firmly attached to a tin can and the other to a common round file. A hole was then pierced through the bottom of the can at its centre, and the file driven backwards and forwards in the hole as if for the purpose of making it larger. At the receiving end B a precisely similar can and file were used, and the file allowed to rest lightly in the hole. Every to-and-fro rasp of the file at A was then distinctly heard at B, even when the can was at some distance from the ear. The same sound was heard when the file at A was laid against any part of the can, but most loudly when it happened to be against a corner or other sharp edge. It was remarkable also, that the sound was heard distinctly even when the file did not touch the can at all, but was merely laid against the wire attached to it, so as to complete the electric circuit without including the can in it. It would seem from this that some mechanical tremor is set up at the loose contact of the file with the wire which is transmitted along the wire to the can. As a variety of this experiment, I removed the can from the wire, and substituted in its place a poker, having the circuit wire firmly attached to its point. When the other end of the poker was put to the ear, and the file applied to the poker at any point, the sound of the distant rasping was distinctly heard. The same was the case when a long brass tube was substituted for the poker, all which very strongly suggests the idea of a mechanical tremor transmitted through the metal from the point of loose contact.

Experiment 2.—In this experiment a common automatic make-and-break, consisting of a vibrating spring worked by a small electro-magnet, was introduced into the circuit at A, and a similar spring, only without the electro-magnet, at B. At B the sound of the vibrations of the springs at A was so distinctly heard, as to at once suggest the idea that the spring at B was itself vibrating. However, I was unable to detect any such vibration, either with the aid of a microscope, or by attaching a small polished bead to the spring and observing in it the reflection of a light. Still it would be rash, I think, to assert that such vibrations were not present, and it is possible that, by more refined experimental means, they may yet be made manifest. It was very noticeable in this experiment that the sound at B got less and less loud as the pressure on the vibrating spring was increased, until it ceased altogether when the contact was made perfectly tight.

Experiment 3.—The sound from the poker in Experiment 1 was so like that produced by the TREVELYAN rocker, that it immediately suggested the employment of that apparatus as the loose contact at B. For this purpose the current was led through the lead block, the rocker, and a brass plate, on which the ball at the end of the rocker rested. When this was done, and the make-and-break set agoing at A, a distinct sound was heard at B, suggesting very strongly the idea that the rocker was in actual vibratory motion. To test this in some measure, I heated the rocker and laid it on the lead block, when two sounds were distinctly heard, one due to the make-and-break, and the other to the heat effect. The one did not seem in the least to interfere with the other. Still farther to test the idea of actual vibration, it occurred to me to try if one rocker could not be made to act as the make-and-break to agitate the other. For this purpose two precisely similar rockers were taken, consisting of two long flat files. These were put edgewise on the lead blocks, with their tails resting on the edges of three-cornered files. The current was sent through the rockers by means of these lead blocks and three-cornered files. One of these rockers was placed at A along with the automatic make-and-break, while the other was placed at B. An arrangement was provided whereby the make-and-break could be at any moment shunted out of the circuit without interrupting the current. The make-and-break was then started, and having ascertained that the rockers at A and B were both sounding, the make-and-break was shunted off in hopes of hearing A and B still continuing to sound from the one acting as make-and-break to the other. These hopes, however, were doomed to disappointment, as, after many trials, I failed to hear any sound after the shunt was made.

Experiment 4.—Being still not satisfied that there was not an actual vibration at B in these experiments, I determined to test for it in another way. This time I took a tin can and riveted into the centre of its bottom a pointed piece of steel wire. The can was fixed to a wooden board, and an arrangement made whereby another pointed piece of steel wire could be moved up opposite to the former piece, and as close to it as might be desired. The current was now led through the can and these pieces of steel, and the make-and-break started as usual, when very minute to-and-fro vibrations of the can were observable, especially when the steel points were not pressing hard against each other but loosely in contact, so that little sparks could be seen between them. To make perfectly certain of this observation, I hope to repeat the experiment with still greater care.

From this experiment, notwithstanding the negative evidence of the others, it seems not unlikely that when a strong interrupted current is sent through a circuit where there is a loose contact, more or less of an actual separation of the surfaces there takes place, so as to make something of a make-and-break similar to the original make-and-break which causes the interrupted current. Should this suggestion be established, it will follow that it is something of the same kind, but only differing in degree, which sends the undulatory currents which transmit musical sounds and articulate speech from any form of microphone transmitter to a similar form of microphone receiver.

As to the cause or causes of this separation of the surface at the loose contact B, or of whatever agitation else it may be which gives forth the sound, it is impossible in the present state of knowledge to speak with confidence. I am inclined, however, to look for one cause at least in that produced by the current at the loose contact. There the resistance and, in consequence, the rise of temperature produced by the current is greatest, and an effect similar to the TREVELYAN rocker will be set up, although immensely smaller in amount.

Experiment 5.—This experiment has reference to the sounds heard in a telephone by means of a microphone transmitter. It is well known that these can be heard with a very weak battery in the circuit, and even with no battery at all, provided the points of the microphone carbon be a little moist. I find that sounds can be heard in the telephone without a battery, and with the carbons apparently quite dry, if we rub the carbons hard together. This rubbing is distinctly heard, and it seems that it must arise in part at least from thermo-electric currents produced by the friction. That such are produced is readily shown by attaching two wires to the terminals of a Thomson's reflecting galvanometer, and to the ends of these wires any two conducting substances. When these substances are rubbed against each other the movements of the spot of light clearly indicate the production of currents. I have roughly tested these currents, and find that they are stronger in proportion as the metals rubbed are wider apart on the theremo-electric scale; but I have found no two substances, even of the same kind, which do not give them slightly. It is just possible, however, that such currents may not be wholly thermo-electric, but that some may be due, as I mentioned in a recent paper to the Society, to the currents suggested by Sir William Thomson as the cause of friction.

IX.—*The Solar Spectrum in* 1877–1878, *with some practical idea of its probable temperature of Origination.* By Piazzi Smyth, F.R.S.E., and Astronomer Royal for Scotland. (Plate II.).

CONTENTS.

Part I.

Although the Spectrum whose linear record is now presented to the Royal Society, Edinburgh, is unfortunately not so perfect as it might have been with better apparatus (but which I did not possess)—yet it represents the labour and expense connected with two voyages in 1877–1878 to Portugal; and many weeks work there in both years, with the sun in a more favourable position for observing really solar, and not telluric, or atmospheric, phenomena, than is ever, at any time, obtainable in Great Britain.*

In fact, it purports to be a spectrum of the sun at an average altitude of about 70°, with everything from the ultra red, to the ultra violet, end,—so far as that is amenable to the human eye and glass transmission in an experimental apparatus;† where prism trains of dispersions from 10° to 50° (between A and H), were employed; magnifying powers from 10 to 20; aper-

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* I should here most thankfully acknowledge, seeing that the work was thereby so greatly facilitated, the extremely liberal and generous conduct of the Pacific Steam Navigation Co. of Liverpool; who, four times over, kindly and safely conveyed all the large packages of scientific instruments, free of expense, in one or another of their several magnificent steam-ships of 4000 tons burthen. These fine vessels start every month on their grandly oceanic voyages to South America *via* the Straits of Magellaen, taking Lisbon in their way; and form an almost luxurious, at the same time that they are both a speedy and yet admirably economical, method of passing and repassing between cloudy Britain, and its favourite little, historic Ally in the clear and sunny South.

Among those to whom my thanks are more particularly due, I trust to be excused for mentioning Captain Hamilton of the *Aconcagua*, Captain Graves of the *Cotopaxi*, Chief Officer Friend of the *Liguria*, Captain Hayes of the *Valparaiso*; and though last, by no means least, Mr Sanderson, the courteous Secretary of the Company, and Reginald Harrison, Esq., the active and ever watchful Medical Officer of Liverpool's most extensive and busy Port.

† Though the apparatus was put together at home, the several important parts of it were furnished by, and are altogether due to, the professional skill of M. Salleron, 24 Rue Pavèe au Marais, Paris; and Mr Adam Hilger, 192 Tottenham Court Road, London.

tures to prisms, and lenses, from 1·0 to 2·25 inches wide; the length of the collimator being 31 inches; and that of the telescope rather more.

The Sun's light was brought to the instrument by a heliostat mirror and lens of long focus, worked by endless screws and managed very steadily for me during the whole of the observations in both years by Mrs PIAZZI SMYTH. Generally speaking too, all the apparatus, though its fittings were rough, answered well within its limits of power; excepting only this anomaly, that between E and F, from some cause I have not yet been able to ascertain, the telescope would not focus accurately; or rather it had two foci thereabouts, and neither of them sharp, no matter how fine the slit was made, or how carefully the prisms were re-adjusted to position of Minimum Deviation for precisely the part of the spectrum there concerned; while a very fine slit, when out of focus, makes some puzzling lines of its own; and may have occasionally increased unduly the number of the thinner ones noted for the Sun.

Again after passing G, and more especially after passing little *h*, the continuous spectrum's light was too faint for good observation. This is indeed a region to be recorded by photography rather than the eye; and it is being so tabulated in a magnificent manner by Mr RUTHERFURD (New York), Mr LOCKYER (London), Dr HENRY DRAPER (New York), M. CORNU (Paris), and many other most able savants. So that for full accuracy, number of lines, and extent of spectral range into the ultra-violet, and more especially the fluorescent regions, their works should of course be referred to. But without presuming to compare with them in any degree, I trust there was no objection to my recording for the violet, as I had done already for the red, end of the spectrum, exactly where both lines, and continuous spectrum light ceased to be visible to the eye; especially as I made rather a point of abolishing the use of coloured glasses, so generally used by other observers, to prevent false glare in the field of view, by employing more or less of preliminary prism-separating power instead, with several unexceptionable advantages.

All this however has merely to do with the ways and means, which may be various with different scientists, towards obtaining one and the same end; viz., procuring a continuous record of an eye-observed and glass-transmitted solar spectrum; with, if possible, some improvement or extension over anything of the same kind yet made public. Now the documents to be competed with are not very numerous. In fact, the only published Solar spectrum that has any claim towards being both large, accurate, *complete*, and registered on an absolute or universal scale, is the map by the late admirable Professor ANGSTROM, of Upsala, worthily called his "Normal Solar Spectrum," and referred to now by savants of all countries. It is about 137 inches long, and contains the places and physiognomies of about 1400 lines.

But, strange to say, ANGSTROM's map has not got Nature's red beginning of the Spectrum at all; though too that beginning contains the grandest group of lines throughout the solar spectrum's whole extent, viz., the colossal band and series of great A. And again, all the latter end of his map, throughout its violet and lavender regions, is not only miserably cramped by the untoward qualities of the Wave-length scale adopted by him,—but is very imperfectly rendered therein, or thereupon, through the failure of his "grating" to show that part of the spectrum well. To such an extent was this the case, that although I could improve little or nothing upon his grand map in the orange and citron regions, and in fact did not see the lines there so clear, strong and black as he has often engraved them,—yet in the violet regions the lines appeared to me so very much clearer, blacker, stronger, and both more numerous and more spread out than in his edition of them, that it was on that account often embarrassingly difficult to identify his few, thin, contracted lines and groups, amongst crowds of grander lines, all of them far more notable.

Hence, if it be asked, in what may the present spectrum document hope to benefit existing knowledge—I beg, with all deference to the labours of others with which I may be, up to the present time, unacquainted, to answer thus—

(1st) In supplying to ANGSTROM's Normal Solar Spectrum its proper and natural head-piece at the Red-end; including not only "great A," but certain other lines beyond it, seldom seen by any one.

(2d) In adding to it a large number of very observable lines and groups of lines throughout the indigo, violet, lavender, and gray Spectral regions; increasing ANGSTROM's total number of lines from 1400, to 2000, nearly.

(3d) In recording all the lines on a scale, equally absolute with Wave-lengths, but more naturally suited for spectral phenomena; because both increasing its numbers in the direction of increase of refrangibility, instead of against it; and giving also, on a scale of equal parts, 4 times as much standing room to lines at the violet end, as when cramped up by the Wave-length method.

(4th) In furnishing an account from direct observations of the whole Solar Spectrum for a more recent date than any of the larger maps now before the public, viz., for the years 1877–8; it still being a question in science whether the Solar radiations alter in quality with time; and if so, in what manner and to what degree.

PART II.

With the above remark I might close this introduction to the present spectrum, but for one feature which came out so strongly day after day, as the observations proceeded, that it formed at last the chief and abiding impression on the mind of him who was privileged through so many weeks to contemplate the scientific glory and mysterious physical complexity of the light of an almost Zenith Sun, with a degree of instrumental power not yet possessed by many persons in the world.

This feature was, the absolutely greater number of lines on approaching the violet end of the spectrum. Beginning at the opposite or red end, there were often there large spaces without any lines at all. Spaces where you seemed to be looking into unfathomable ocean depths of nothing but pure, elemental scarlet light; and not even the thinnest spider's thread of a line was floating on their surface anywhere. But in further advance along the spectrum, first in the citron, and then in the green, the lines were evidently more numerous and often thicker; and in the glaucous region more abundant still. While after passing F, a new feature began to appear; for amongst the other and stronger lines, faint visions of graduated bands and groups of markings from the extreme distance almost floated into view like ghosts, and became at length so numerous as almost to dispute standing room with one another.

Continually too, with every further advance towards the violet, these graduated bands of close fine lines became more and more pronounced, occasionally including some decidedly strong lines; while amongst *them* again were not unfrequent specimens of perfectly gigantic size; and this too although I was continually decreasing the dispersive power of the spectroscope (after having passed the spectrum's most luminous portion), to half, or a third, or even a fourth only of what it was before.*

Now there are many very thick lines in that other grand Solar Spectrum Map of the world in the present age, viz., Professor KIRCHOFF's; but somehow, I was never much impressed with their being a great deal more than a mere stretching out by a new hand, not KIRCHOFF's own, of the exaggerated length of the violet in all uncorrected prism representations. But here, in these observations in Portugal, what with the heat of the atmosphere, and the blinding light outside the house, and the magnificent action of the prisms with large apertures and powerful dispersions, causing one to travel slowly, and most carefully, making micrometer observations all the time, over immense angular distances, from one resplendent colour region of inimitable purity and ravishing beauty to another, there was first of all a reality of impression conveyed, respecting the awful supernal temperatures of those celestial fires; fires containing not only so much red and yellow, but such sublime blue and surpassing violet radiations; plunged into whose higher degrees, therefore, anything earthly would be utterly dissipated and vanish; and then it was exactly in the very culminating regions

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* This was in fact adapting each part to our Wave-number Scale; for, without such reduction, a prism formed spectrum is nearly sixteen times longer in the violet, than it is in the red, region, as compared with a diffraction spectrum.

of those violet-hot furnaces that the more gigantic, as well as the numerous thinner lines, and all of them sharp-edged and well-defined, appeared with almost a personality, in their most marked physiognomies, about them; and were found continually multiplying with every further advance in the direction of greater refrangibility. This continual increase in the number of the lines almost reminded one, beginning at the red-end of the spectrum, of the few and far between individuals, you see by rail-road side when travelling through wild hills and Caledonian moors; and then as you go on through the spectrum colours, the lines increase, just as the human figures do when you approach the house-covered suburbs of London. While finally the spectral scenes of closely standing ranks behind ranks of lines between little *h* and great H, is like the crowds of passengers in Cheapside itself. And further, when at last all light itself fails and there is no more spectrum to be seen by the human eye through glass lenses,—you feel that you have not passed beyond, or even arrived at, by any means the last, or the least, or the most closely packed of those peculiar existencies, but are more probably left in the very thick of their legions still.

Then how important in appreciating, or rather merely approximating to, the temperature of the Sun, the study of the mere statistical arrangement of the lines in its spectrum must be; if, indeed we can depend on the chemical elements being similar there, on the whole, to what they are on the earth! So at least I thought on that magnificently practical occasion; knowing well what is already so often remarked among spectroscopists, that in chemical investigations so long as we confine ourselves to the temperature of lamp-flame, the observable spectral lines are chiefly in the red, and only 2 or 3 of *them* are identifiable with solar lines; while when we introduce the higher temperature of the electric spark, an immediate increase of lines in the green and blue is noticed, and a far greater number of solar correspondences obtained.

Having therefore collected about 5000 spectroscopic observations from various sources, and reduced them all to one and the same absolute scale of Wave-number, I have sub-divided them into the following six steps of temperature.

Step 1. Lowest temperature, much below freezing. This being afforded by the telluric lines in the day-light sky spectrum, when a ray of day-light from beyond traverses a long stratum of the earth's absorbing atmosphere in the upper regions. The data here are only 116 in number, and are partly taken from ANGSTROM's solar chart, and partly from my own observations.

Step. 2. Ordinary vital temperature, say 68° F. This has been presented by the absorption spectra of glasses and liquids printed by the Royal Society, Edinburgh, in my paper of last year; the data being 719 in number.

Step. 3. Lamp-flame temperatures; these are taken mainly from M. Lecoq de Boisbaudran's admirable observations, discussed and arranged for this purpose by myself, and offer 370 data.

Step. 4. Electric sparks 1 inch long; for this at present I have only one series of measures; but that is of a rather collective order; being my own observations of *air* in an end-on gas-vacuum tube; its data being 221 in number, as published by the Royal Scottish Society of Arts in their Transactions for 1878–79.

Step 5. Electric sparks 2 inches long; these are taken also from M. de Boisbaudran's admirable series of apparently all the simple substances known in chemistry as being easily amenable to the heating effect of the above spark. The data are 1048 in number.

Step 6. Electric sparks of 6 inches and more long; and very much further raised in temperature by the use of condenser and Leyden-jar apparatus. This is an extensive series of all the known chemical elements, as experimented on by Thalen, Angstrom, Bunsen, Kirchoff, Plucker, Huggins, and others, and probably represents the highest temperature yet attained artificially. The data here are 2685 in number.

These several collections are exhibited in their numerical arrangement through the spectrum in Part IV., and graphically in the plate appended, with the effect of showing that for every increase of temperature, the maximum of spectroscopic phenomena is found farther and farther removed from the red, and towards the violet; so that—

Step 1	has its maximum	in about W.N.	39,000
Step 2	,,	,,	41,000
Step 3	,,	,,	47,000
Step 4	,,	,,	49,000
Step 5	,,	,,	49,000, and
Step 6	,,	,,	51,000.

Now therefore comes the question, as to what is the similar spectrum place of the maximum of Solar Activity as exhibited by the number, size, and position of its lines?

If we take Angstrom's Normal Solar Spectrum, then according to the numerical columns in Part IV., the maximum of its 1410 lines (treated as the other steps are, so as to give double weight to thick and intense lines over thin and faint ones), occurs at 55,000 of the Solar Spectrum scale. But as I have already indicated that the violet end of the Natural Solar Spectrum is cribbed and confined most lamentably in that map, I take my own Lisbon solar spectrum with 2016 lines, and can state according to the numbers also in Part IV., and the last figure in the plate, that its maximum is rather in 61,000 of W. N. spectrum place; and that it ought even to have, though unseen by man through glass, about as much more length still in that ultra violet direction; just as indeed, the fluorescent observers have already discovered with their peculiar apparatus.

Wherefore what a result, we have hereby now obtained. Not free, I must confess, from innumerable little causes of discrepance, and uncertainty from variation of details of instruments and modes of observing, between one spectroscopist and another; but invested with a remarkable breadth of common-sense appreciation of a something all important, about what the public would call degrees of heat. And which, though not yet capable of being employed very positively for science itself, may at least and at once induce many scientific men to be more cautious in future as to what heating methods they should strive to employ, and be careful to define and record the temperature results thereby attained, whenever they compare spectroscopically, terrestrial chemical elements in incandescence, with the Solar elements in a similar condition. For, by how much the deflagrating temperatures of the most powerful electric sparks yet prepared by man, exceed the lower than freezing temperatures of the upper air,—by just about as much, and even a little more too, is the former exceeding high temperature surpassed by the almost unspeakably still higher temperature of the surface of the Sun, inch for inch, within its own domain.

Part III.

THE SOLAR SPECTRUM ITSELF

at the date 1877–1878.

This is a complete spectrum from one end to the other of everything visible to the *eye* through *glass* lenses and prisms, under dispersion powers of 33° (A to H) at the red, down to 10° (A to H) at the violet or lavender end; and with magnifying powers of 10 to 20 on the telescope of inspection; the light being reflected to the slit occasionally by a silver-on-glass reflector, but more generally by a glass plate quick-silvered on the back.

Hence this spectrum necessarily terminates a little beyond the H lines, and has no pretence of competing with metallic reflections, quartz lenses, fluorescent eye-pieces and photographic registrations, for their capacities in the more refrangible regions. It is simply an eye record of the luminous phenomena which are capable of being transmitted through *glass*.

On the other hand it is peculiarly a spectrum of *solar* lines with the least possible *telluric* admixture, as the observations were made at Lisbon, in June and July, and always near the middle of the day when the sun had an altitude of nearly 70°. It is also a peculiar record of solar spectrum colours, as direct and pure as the narrowest slit, the elimination of reflections of adjacent portions of the spectrum from the sides of the prisms, and the non-employment generally of any coloured glass screens could make it.

The spectroscope was an experimental one prepared by myself.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA. from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	At Lisbon in 1877, July; and in part revised there in June 1878. Time of observation generally near Noon, when altitude of sun = 70° nearly, and thickness of atmosphere looked through = 1·06 (a Zenith-atmosphere being assumed = 1·00). This first portion was observed with the Aurora Spectroscope. Dispersion = sometimes 14°, sometimes 33° from A to H, mag. power of telescope = 10.				The four first places within parentheses are from a grating photograph by Capt. W. de W. Abney, R.E., F.R.S.		(Temporary Conclusions only, up to great **A.**)		
	Light of Continuous Spectrum of Sun begins at *Ultra-Red end* of Spectrum, at or near to, ...			48·296			27 800		
									1460
Ultra-Red.	First line observed, a dark line on said continuous spectrum, ...	2	│	49·721	(29 260)		29 260		
									420
	A strong line, called X, . .	**4**	┃	**50·144**	**(29 680)**	Unknown, but apparently Solar rather than Telluric.	**29 680**		
									150
	A fine, *i.e.* thin, line, ...	1	│	50·333	(29 830)		29 830		
									650
……… …	Ultra-Red ends and Crimson-Red begins, more or less, approximately.						(30 000)		
	A fine line, ...	1	│	51·000			30 480		
									120
	Haze intervenes and accompanies the next three lines, ...	0·5	⁞⁞⁞						
	Fine line, ...	1	│	51·132			30 600		
									80
Crimson-Red.	Fine line, ...	1	│	51·203			30 680		
									40
	Fine line, ...	1	│	51·258			30 720		
									120
	Very strong line Y, **first side of,** **middle of,** **second side of,**	**9**	┃	**51·386** **51·403** **51·413**	**(30 860)**	Chemical origin unknown, but apparently Solar rather than Telluric.	**30 840** **30 860** **30 870**	20 10	
									110
	Band of lines, whereof line 1, . .	3	│	51·527			30 980		
									50
	line 2, . .	2	│	51·601			31 030		
									60
	line 3, . .	1	╷	51·674			31 090		
									60
	line 4, . .	1	╷	51·740			31 150		
									60
	line 5, . .	1	╷	51·808			31 210		
									690
Crimson-Red.	Very faint line, supposed to be the Z of low Sun spectra, ...	1	╷	52·624		Probably Telluric.	31 900		
									870

N.B.—When any of the above lines, Z excepted, are seen at all (in the high-sun spectrum), they are usually seen very black; an effect in part probably due to the ultra-faintness of the background of continuous spectrum they are projected upon; and, in part, to their being not telluric, but solar lines; so that instead of being seen at their faintest, as the former are, they are seen, if not actually at their strongest, at least exceedingly strong, and stronger beyond comparison than acknowledged telluric lines, such as B and α, in a high-sun spectrum, through a minimum thickness of terrestrial atmosphere; proper care being of course always taken by the observer to prevent false glare of brighter parts of the spectrum entering the field with these lines.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	A probable fine line,	0·5	|	53·730			32 770		120
	Another probable fine line,	0·5	|	53·900			32 890		100
	Excessively faint and fine line,	0·2	·	54·018			32 990		37
Crimson-Red.	Very faint thin line,	0·3	·	54·086			33 027	26	
	Another,	0·3	·	54·093			33 053	30	
	Another,	0·5	·	54·129			33 083	21	
	A stronger line,	0·7	|	54·163			33 104	31	
	A stronger line,	1·0	|	54·196			33 135	30	
	Stronger and blacker,	1·5	|	54·227			33 165	15	
	Strong, clean and black,	2·0	|	54·256			33 180	18	
	Strong, sharp and black,	3·	|	54·283			33 198	16	
	Very strong, black, thick, and sharp,	**4·**	▎	**54·308**			**33 214**	26	
	Stronger, blacker, thicker,	**5·**	▍	**54·331**			**33 240**	15	
	Very strong, black, sharp edged,	**5·**	▍	**54·353**			**33 255**	17	
	The same: haze between the lines,	**6·**	▍	**54·374**		Unknown, but probably Solar rather than Telluric.	**33 272**	9	
	The same: do. do.	**6·**	▍	**54·394**			**33 281**	14	
	Strongest of the whole: do. do.	**7·**	▌	**54·413**			**33 295**	11	
	Rather fainter: do. do.	**5·**	▍	**54·431**			**33 306**	12	
	Still fainter: do. do.	3·	|	54·447			33 318	12	
	Fainter still, and thinner: do.	1·	|	54·461			33 330	30	

The above 17 lines, exquisitely graduated, sharp, clean, and strangely black, like admirably engraved lines on a copper plate filled in with black printing ink, form the preliminary band before great **A**. Origin in chemistry unknown.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
Crimson-Red.	The first of a grand bundle of close lines, with haze between,	2	|	54·481		Unknown, but probably Solar rather than Telluric.	33 360		10
	Second do. do.	3	|	54·492			33 370		10
	Third do. do.	**4**	▎	**54·503**			**33 380**		5
	Fourth do. do.	**4**	▎	**54·515**			**33 385**		7
	Fifth do. do.	**5**	▍	**54·528**			**33 392**		8
	Sixth do. do.	**5**	▍	**54·541**			**33 400**		8
	Seventh, near middle of bundle,	**6**	▍	**54·551**	**33·402**		**33 408**		
	An eighth, probable,	?	?						
	Ninth, probable,	?	?						22
	Tenth, or last,	**5**	▎	**54·578**			**33 430**		
	A pale space, but probably of far finer lines intervenes, thus and then—	2	⁙						40
	First side of a thick, dark line,	**8**	█	**54·607**			**33 470**	10	
	Second side of do.			**54·621**			**33 480**		20

The above 12 entries form the great **A** line itself, the colossus of all the Solar spectrum lines, and its chemical origin unknown.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
	A fine, *i.e.*, thin, line,	1	|	54·670			33 500		70
	Very fine line, haze to right,	0·7	⁝	54·760			33 570		200
	Finest line,	0·2	·	55·041			33 770		50
	Suspected finest line,	0·1	·	55·110			33 820		75
	Do. do.	0·1	·	55·210			33 895		65
	Do. do.	0·1	·	55·292			33 960		140
	Do. do.	0·1	·	55·409			34 100		20

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed, Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data, from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Suspected finest line,	0·1	ı	55·516			34 120		100
	Rather stronger line,	0·3	ǀ	55·658			34 220		30
	Fine line,	0·2	ǀ	55·703			34 250		33
	Fine line,	0·2	ǀ	55·745			34 283		127
	Hazy line,	0·3	:ı:	55·873			34 410		80
	Suspicion of a line,	0·1	·	55·912			34 490		10
	Fine line,	0·3	ǀ	56·016			34 500		60
	Do.	0·3	ǀ	56·049			34 560		10
	Do.	0·3	ǀ	56·136			34 570		30
	Do.	0·3	ǀ	56·170			34 600		50
	Stronger hazy line,	0·5	:ı:	56·238			34 650		40
	Do. do.	0·5	:ı:	56·288			34 690		32
	Stronger and clearer line,	1	▌	56·344	34 722	Telluric water-vapour.	34 722		38
	Do. do.	1	▌	56·394			34 760		27
	Do. do.	1	▌	56·433			34 787		8
	Fainter line,	0·5	ı	56·446			34 795		37
	First faint line of a band,	1	ǀ	56·496		Telluric water-vapour.	34 832		15
	Second stronger,	1	ǀ	56·516			34 847		17
	Third strongest,	2	ǀ	56·541			34 864		26
	Single line,	1	ǀ	56·576			34 890		23
Crimson-Red.	First and strongest line of a band,	2·	▌	56·611		Telluric water-vapour.	34 913		11
	Second rather weaker,	1·5	▌	56·623			34 924		9
	Another still weaker,	1·	▌	56·640			34 933		14
	Last, weakest of all,	1·	ǀ	56·658			34 947		33
	Strong line of a band,	2	▌	56·701			34 980		12
	Weaker line,	1	ǀ	56·721			34 992		17
	Last and weakest line,	1	ǀ	56·746			35 009		27
	Single line, strong,	2	▌	56·784	35 036		35 036		14
	Very faint Line,	0·3	ı	56·801		Telluric water-vapour.	35 050		34
	Fine line,	1·	ǀ	56·851			35 084		9
	Stronger line,	2·	▌	56·866			35 093		36
	Very faint double line,	0·7	ǁ	56·914			35 129		3
	Fine line,	0·5	ǀ	56·922	35 152		35 132		27

The above bracketed lines, 34 722 to 35 132 W.-N., constitute the preliminary band, before the little *a* band; it is apparently composed of water-vapour lines, and increases in number and thickness of lines egregiously with a low Sun and in warm, damp weather.

CRIMSON-RED, as the colour of the continuous spectrum, ends at 35,000; and RED begins.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed, Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data, from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
	Fine line,	1	ı	56·960			35 159		19
	Fine line,	1	ı	56·984			35 178		34
	Fine line,	1	ı	57·036			35 212		31
	Fine line,	1	ı	57·084		Telluric watery vapour.	35 243		9
	Stronger line,	1·5	▌	57·098	35 252		35 252		9
	Fine line,	1	ı	57·110			35 261		9
	Fine line,	1	ı	57·123			35 270		10
	Strongest line yet,	3	▌	57·142			35 280		12
	Fine line,	1	ı	57·158			35 292		16
RED.	Faintest line of a bandelet,	0·5	ı	57·182		Telluric watery vapour.	35 308		14
	Stronger of do.	0·7	▌	57·204			35 322		7
	Strongest of do.	1·5	▌	57·214			35 329		
	Centre of a clear space,			57·233	35 339		35 342		
	Strongest line of a bandelet,	2·	▌	57·253		Telluric watery vapour.	35 346		17
	Second strongest,	1·5	▌	57·262			35 363		17
	Last and weakest,	0·7	ı	57·288			35 380		25

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Frauenhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data, from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Strong line,	2·	▌	57·323			35 405		17
	Strong line,	1·7	▌	57·350		Telluric watery vapour.	35 422		11
RED.	Fine line,	1	│	57·366			35 433		13
	Do.	1	│	57·381			35 446		9
	Do.	1	│	57·395			35 455		13
	Do.	1	│	57·413	35 468		35 468		30

The above bracketed lines, 35 243 to 35 468 W.-N., form the band of little *a* itself; a terrestrial water-vapour group, of which the lines increase so in both number and blackness, with a low Sun and in warm, moist weather, as to make the whole band one black club, excepting the light chink in the middle; though that may also be blocked at last. In this condition the so-called little *a*, and its preliminary band, look gigantic even as compared with great **A** and its preliminary band; though with a high Sun, great **A** is the grandest and blackest line in the whole spectrum.

From this point begin the observations of 1878, at Campolide, near Lisbon, with a Solar Spectroscope, 3 prisms. Dispersion = 28°, A to H; and a telescope with mag.-power = 20. Date = June 21. Time = 9h. 50m. A.M. The Red colour of Continuous Spectrum is a glorious background for the delineation of the black spectral lines.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Frauenhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data, from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Suspicion of fine line or band,	0·2	⁝.	12·087			35 498		11
	Do. graduating to left,	0·2	.⁝	12·127			35 509		18
	Suspected fine line,	0·2	ı	12·181			35 527		14
	Fine line certain,	1·	│	12·228	35 541	?	35 541		27
	Suspected fine line,	0·3	⁝	12·296			35 568		24
	Do. do.	0·3	⁝	12·355			35 592		35
	Very fine line,	0·6	│	12·450			35 627		44
	Fine line,	1·0	│	12·560			35 671		57
	Suspected fine line,	0·5	⁝	12·700			35 728		3
	Do. do.	0·5	⁝	12·708			35 731		19
	Do. do.	0·4	⁝	12·756			35 750		80
	Do. do.	0·5	⁝	12·950			35 830		34
	Do. do.	0·4	⁝	13·035			35 864		32
	Finest line,	0·6	│	13·118			35 896		32
	Do.	1·0	│	13·198			35 928		15
	Suspected fine line,	0·5	⁝	13·239			35 943		4
	Do. do.	0·5	⁝	13·242			35 947		53
	Do. do.	0·5	⁝	13·380			36 000		38
RED.	Fine line, double—1st line,	0·7	│ } ││ {	13·482 }	36 039	Telluric watery vapour.	{ 36 038 }	8	
	2d line,	0·7	│ } ││ {	13·504 {			{ 36 046 {		32
	Suspected fine line,	0·5	⁝	13·590			36 078		27
	Fine line, double—1st line,	0·8	│ } ││ {	13·661	36 108		36 105 }	11	
	2nd line,	0·6	│ } ││ {	13·693	36 118		36 116 {		8
	Suspected fine line,	0·4	⁝	13·720			36 124		30
	Very certain, plain double line, but hazy—1st line,	2	⁞│⁞ } ⁞│⁞ ⁞│⁞	{ 13·823	36 152	Telluric watery vapour.	36 154 }	22	
	2nd line,	2	⁞│⁞ } ⁞│⁞ ⁞│⁞	{ 13·880	36 171		36 176 {		34
	Strongest line yet, but hazy,	3	⁞┃⁞	13·963	36 214		36 210		22
	Fine line, hazy,	1	⁞│⁞	14·030	36 240		36 236		27
	Strong line of a band, but hazy,	3	⁞┃⁞	14·115	36 265		36 263		41
	Less strong line, also hazy,	2	⁞│⁞	14·200	36 292	Telluric watery vapour.	36 304		20
	Less strong still,	1	⁞│⁞	14·270	36 321		36 324		24
	Less still,	0·8	⁞│⁞	14·350	36 343		36 348		12
	Very faint and close,	0·3	. .	14·380	36 362		36 360		36
	Hazy band, graduating down to right hand—beginning,	} 1·5	⁞⁞⁞. }	14·487	36 396		36 396	18	
	end of,			14·534			36 414		23
	Suspected fine line,	0·5	⁝	14·600	36 437		36 437		17
	Do. do.	0·5	⁝	14·632			36 454		19
	Fine line, double, sharp—1st line,	0·7	│ } ││ {	14·673	36 471		36 473 }	4	
	2nd line,	0·7	│ } ││ {	14·687			36 477 {		21

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
RED.	Stronger fine line, double, sharp—								
	1st line, ...	1·0	│ { ││ }	14·735			36 498 }	4	
	2nd line, ...	1·0	│	14·756			36 502 }		21
	Stronger line, clean and sharp, . .	2	│	14·800	36 523		36 523		9
	Fine line of band, ...	1	│) (	14·835			36 532		16
	Do. do.	1·5	│ { ││┃ }	14·876		Telluric.	36 548		12
	Do. stronger, . . .	1·5	│	14·910			36 560		6
	Stronger still, fine and sharp, . .	3	┃	14·930	36 565		36 566		12
	Fine line, ...	0·6	│	14·958			36 578		4
	Do.	0·6	│	14·975			36 582		14
	Do.	0·7	│	15·000			36 596		8
	Stronger fine line and sharp, . .	2	┃	15·022	36 603		36 604		14
	Fine line, ...	0·5	│	15·054			36 618		18
	Stronger line, ...	1·0	│	15·103			36 636		27
	The step line before B's preliminary band, ...	2	┃	15·176	36 663	Telluric.	36 663		

Here begin the grand bands of fine lines before the great **B** line, of which we made three independent sets of observations on June 15 and 19, near Noon A.M., and P.M., with dispersions varying from 28° up to 50° (between A and H). The following Wave-number places are a mean of the whole.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	WAVE-NUMBER-PLACE of every line.	Differences of pairs.	WAVE-NUMBER-PLACE of single lines, and Centres of doubles.	Differences.	
RED.	The step line repeated, ...	2·0	┃	36 663		36 663		**Telluric lines.**
	Very faint line, ...	0·1	│	36 679			31	
	Preliminary band begins.							
	First pair—1st component line, .	0·5	│ { ││ }	36 691	3	36 692		**Telluric lines, supposed of dry gas.**
	2nd do. do. . .	0·5	│	36 694			27	
	Second pair—1st component line, .	0·7	│ { ││ }	36 717	4	36 719		
	2nd do. do. .	0·7	│	36 721			25	
	Third pair—1st component line, .	1·0	│ { ││ }	36 742	5	36 744		
	2nd do. do. . .	1·0	│	36 747			26	
	Fourth pair—1st component line, .	1·5	│ { ││ }	36 767	6	36 770		
	2nd do. do. .	1·5	│	36 773			25	
	Fifth pair—1st component line, .	1·8	│ { ││ }	36 792	6	36 795		
	2nd do. do. . .	1·8	│	36 798			22	
	Sixth pair—1st component line, .	2·0	│ { ││ }	36 814	7	36 817		**Telluric lines, supposed of dry gas.**
	2nd do. do. . .	2·0	│	36 821			21	
	Seventh pair—1st component line, .	2·5	│ { ││ }	36 835	6	36 838		
	2nd do. do, .	2·5	│	36 841			20	
	Eighth pair—1st component line, .	2·5	│ { ││ }	36 855	5	36 858		
	2nd do. do. .	2·5	│	36 860			18	
	Ninth pair—1st component line, .	2·0	│ { ││ }	36 874	5	36 876		
	2nd do. do. .	2·0	│	36 879			16	

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	WAVE-NUMBER-PLACE of every line.	Differences of pairs.	WAVE-NUMBER-PLACE of single lines, and Centres of doubles.	Differences.	
	Tenth pair—1st component line,	1·5	ǀ ǀ ǁ	36 891	3	36 862		
	2nd do. do.	1·5		36 894			15	
	Eleventh line, single,	1·0	ǀ	36 907		36 907		

The above concludes the "preliminary" band of Great **B**, and the double lines are eminently sharp, clear, well-defined both within and without, having no haze whatever about them.

Next begins the so-called "attached" band of Great **B**.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	WAVE-NUMBER-PLACE of every line.	Differences of pairs.	WAVE-NUMBER-PLACE of single lines, and Centres of doubles.	Differences.	
	First pair—1st component line,	0·3	ǀ ǀ ǁ	36 924	4	36 926		Telluric lines, supposed of dry gas.
	2nd do. do.	0·3		36 928			10	
	Second pair—1st component line,	0·5	ǀ ǀ ǁ	36 934	3	36 936		
	2nd do. do.	0·5		36 937			7	
RED.	Third pair—1st component line,	0·8	ǀ ǀ ǁ	36 942	2	36 943		
	2nd do. do.	0·8		36 944	5		6	
	Fourth pair, or single line ?	1·0	ǀ	36 949	5	36 949	5	
	Fifth do. do. ?	1·0	ǀ	36 954	4	36 954	4	
	Sixth do. do. ?	0·8	ǀ	36 958	4	36 958	4	
	A strong certain single line,	2·0	❙	36 962	6	36 962	6	
	Another like it,	2·0	❙	36 968	7	36 968	7	
	Another rather fainter,	1·5	ǀ	36 975		36 975	7	
	Great **B** line, begins with a bundle of fine lines—1st edge whereof,	3		**36 982**		**36 982**	2	
	2nd do.			**36 984**		**36 984**		
	A pale space intervenes, shaded by apparently infinitely fine, close lines,						6	
	A strong terminal line,	2	❙	**36 990**		**36 990**		

The above terminates the whole of the very beautiful arrangement of great **B** and its bands; supposed to be due to telluric influence, because it thickens when the sun is low in the sky, but the particular element, or combination of elements to which it is due, is not yet known. All the lines from 36 692 to 36 990 blacken immensely as the Sun goes down.

The beauty of the compound and rythmical structure of the lines is much enhanced by the magnificent full and perfect red on which they are depicted when the Sun is high, and no false glare from other parts of the spectrum enters the field of view.

With W.-N. 37 000 the Red of the Continuous Spectrum verges towards a scarlet-red, more or less, partly depending on the brightness of the light.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Suspected fine line,	0·3	ǀ				37 013		19
	Do. do.	0·3	ǀ				37 032		11
	Certain fine line,	1·0	ǀ		37 043		37 043		41
	Suspected fine line,	0·3	ǀ	9·765			37 084		9
	Do. do.	0·3	ǀ	9·782			37 093		8
	Do. do.	0·3	ǀ	9·834			37 101		21
	Do. do.	0·3	ǀ	9·862			37 122		21
Scarlet-Red.	Do. do.	0·3	ǀ	9·920			37 143		49
	Certain fine line,	1·5	ǀ	10·050	37 195		37 192		50
	Suspected fine line,	0·5	ǀ	10·160	37 247		37 242		66
	Certain fine line,	1·0	ǀ	10·328			37 308		35
	Suspected fine line,	0·5	ǀ	10·426			37 343		183
	Certain very fine line,	1·0	ǀ	10·913			37 526		27
	Certain fine line,	1·6	ǀ	10·992	37 553		37 553		85
	Very fine line,	1·0	ǀ	11·268			37 638		44

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
Scarlet-Red.	Suspected fine line, ...	0·4	ı	11·407			37 682		
	Do. do.	0·4	ı	11·465			37 700		18
	Fine line, ...	1·0	|	11·667	37 764	Calcium.	37 764		64
	Do.	1·0	|	11·740			37 789		25
	Strongest line yet, but sharp and clean,	2·5	|	11·813	37 816	Calcium.	37 816		27
	Fine line, ...	1·	|	12·005	37 898		37 892		76
	Suspected fine line, ...	0·5	ı	12·143			37 940		48
	Stronger than previous strongest, or "Half-way line" between B and C.,	3·	▌	12·463	38 040		38 040		100
	Suspected line, ...	0·5	ı	12·570			38 073		33
	Do. do.	0·5	ı	12·645			38 100		27
	Strong line, ...	1·5	|	12·704	38 116	Iron.	38 116		16
	Do.	1·5	|	13·037	38 238		38 240		124
	Strong line, and rather thick, probably double, ...	2	▌	13·200	38 291	?	38 291		51
	Fine line, ...	1	|	13·638	38 465		38 459		168
	Suspected fine line, ...	0·5	ı	13·734			38 486		27
	Suspected narrow band, . . .	0·5	⁞	13·830	38 502		38 504		18
	Double line, sharp and thin—								
	1st component, ...	1·5	| } ||	13·906	38 530		38 528	8	24
	2nd do.	1·4	|	13·928			38 536		
	Fine line, ...	1·5	ı	14·037	38 570	Tell. water vapour.	38 570		34
	Suspected faint band, . . .	0·5	⁞	14·130	38 600		38 600		30
	Certain fine line, ...	1·5	|	14·252	38 640	Iron.	38 639		39
	Suspected fine line, ...	0·5	ı	14·305			38 654		15
	Certain fine line, ...	1·0	|	14·355	38 678		38 672		18
	Haze on left of C line, . . .	0·3	▒	14·450			38 697		25
	Left side of thick C line, .	**5·**	█	**14·473**			**38 702**		5
	Centre of C line, . .	**10·**			**38 706**	Hydrogen.	**38 706**	7	
	Right side of C line, . .	**5·**		**14·490**			**38 709**		
	Haze on right of C line, . . .	0·3	▒	14·508			38 716		7

The haze, dark and ugly looking about **C**, or Scarlet Hydrogen, may tend to show that the Solar hydrogen is in a disturbed state. Otherwise the Scarlet-red of the continuous spectrum hereabouts is brilliant in the extreme.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
Scarlet-Red.	Very fine line, ...	1·5	ı	14·610			38 750		34
	Do. do.	1·5	.	14·660		Tell. water vapour.	38 765		15
	Do. do.	1·5	ı	14·728			38 790		25
	Stronger fine line, ...	2·5	▌	14·775	38 806	Iron.	38 806		16
	Fine line, ...	1·8	ı	14·818	38 816	Tell. water vapour.	38 816		10
	Very fine line, ...	1·	.	14·995	38 882		38 880		64
	Do. do.	1·	.	15·018			38 888		8
	Fine line, ...	1·5	ı	15·112			38 919		31
	Do.	1·5	ı	15·180			38 939		20
	Fine line and hazy, perhaps double, .	1·5	⁞▌⁞	15·275			38 968		29
	Rather stronger line and sharp, .	2·	▌	15·325	38 981	Tell. water vapour.	38 983		15
	Very fine line, ...	1·	ı	15·356			38 987		4

(SCARLET colour ends, ORANGE begins hereabouts.)

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
Orange.	Very fine line, ...	1·	.	15·404	39 010		39 010		23
	Fine line and hazy, ...	1·	⁞▌⁞	15·480			39 032		22
	Certain fine line, ...	1·5	|	15·660	39 088	Calcium.	39 093		61
	Band, probably of 5 or 6 very close lines. Beginning, .	1·	≡	15·695	39 115	Barium. Tell. water	39 112	23	19
	End of Band,	1·	≡	15·773	39 135	Calcium.	39 135		

♀ June 21, 0h. 15m. Reset Prisms to Min. Dev. for Part.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
	Band repeated 1st line of 5 or 6, .	1·	≡	10·447	39 105	Tell. watery	39 104	30	
	last line of do.,	1·	≡	10·510	39 135	vapour, &c.	39 134		15

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Very fine line, ...	1·	|	10·565			39 149		
	Very fine line, ...	1·	|	10·620		?	39 160		11
	Fine band graduating down to right hand } 1st and strongest line, . . .	2·	| } |||| {	10·690	} 39 178		{ 39 182	} 8	22
	last, and weakest, .	0·2	|	10·712			{ 39 190		
	Single fine line, ...	1·	|	10·755			39 202		12
	Stronger line. Double in Angstrom,	3·	❙	10·820	39 231	?	39 228		6
	Faint line, ...	1·	|	10·885			39 252		24
	Faint line, ...	1·	|	10·928		Iron.	39 264		12
	Suspected line, ...	0·3	·	10·955			39 274		10
	Strong line, ...	3·	|	11·045	39 306	Iron and Calcium.	39 303		29
	Suspected line, ...	0·3	·	11·090			39 320		17
	Certain line, but faint and hazy, .	0·5	⁞⁞	11·154			39 341		21
	Strong line, hazy and faint, . .	2·	⁞❙⁞	11·290	39 383	Calcium.	39 386		45
	Still stronger line and sharper, . .	3·	❙	11·473	39 450	Calcium.	39 452		66
	Hazy band suspected, . . .	1·	⋮	11·584			39 488		26
Orange.	Fine sharp line, ...	1·5	|	11·635	39 500	Iron.	39 500		12
	Double line, very sharp, 1st component,	2·	| } || {	11·796		Iron.	39 563	} 11	63
	2d do. .	2·	|	11·828			39 574		
	Fine line suspected, ...	0·5	·	11·878			39 590		16
	Very fine, or thin, line, . . .	1·	|	11·917			39 603		13
	Stronger line, ...	2·	|	11·976	39 621	Iron.	39 623		20
	Do. do.	2·5	|	12·040		Iron.	39 648		25
	Strongest line yet, ...	**4·**	❚	**12·185**	**39 692**	Iron.	**39 694**		46
	Strong line, ...	3·	|	12·305	39 734	Iron.	39 735		41
	An important group for identification.								
	Fine band suspected, ...	0·4	⋮	12·460			39 788		53
	Fine line suspected, ...	0·2	·	12·554			39 819		31
	Do. do.	0·2	·	12·740			39 880		61
	Do. do.	0·2	·	12·820			39 905		25
	Very thin line, ...	0·5	|	12·890			39 930		25
	Certain fine line, ...	1·	|	12·957		Iron.	39 950		20
	Do. do.	1·	|	13·027		Iron.	39 975		25
									49

ORANGE colour ends here, and AMBER begins.

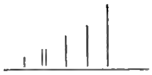
In the Solar spectroscope, when glare is prevented by a preliminary prism, rather than by coloured glass, the beauty and transparency of the amber colour of this part of the spectrum is something most exquisite to behold.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
	Very thin line, ...	2	|	13·182			40 024		
	Do. do.	2	|	13·235			40 040		16
	Fine line, 1st of three, ...	3	|) ||| (	13·339		?	40 070		30
	2nd do.	3	|	13·383	40 086	Iron.	40 086	16	
	3rd do.	3	|	13·420		Iron.	40 099	13	
	Suspected fine line, ...	0·5	|	13·510			40 129		30
	Very fine line, ...	1·	|	13·560			40 145		16
	Fine line certain, ...	1·5	|	13·667		Iron.	40 178		33
Amber.	Last edge of band beginning to left, .	1·	≣[	13·750	40 207	Iron, &c.	40 206		28
	Line, hazy, ...	1·	⁞❙⁞	13·810		Iron.	40 230		24
	Suspected line, ...	0·5	|	13·895			40 259		29
	Do. do.	0·5	|	13·973		?	40 286		27
	Fine and sharp double line—								
	1st component, ...	2·	| } || {	14·048 }	40 311	Iron, &c.	{ 40 310	8	24
	2nd do.	2·	|	14·065 }			{ 40 318		
	Fainter, wider double line—								
	1st component, ...	1·5	| } ¦¦ {	14·104		Iron.	40 332	8	14
	2nd component, ...	1·5	|	14·140		?	40 340		
	Suspected fine line, ...	0·5	|	14·186			40 350		10
	Do. do.	0·5	|	14·250			40 378		28
	Certain fine line, ...	1·5	|	14·288		?	40 390		12
									33

Colour of the Continuous Spectrum at the Place.	Object observed, generally a black, fixed Fraunhofer Line.	Intensity of black. or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Faintest haze band—1st edge,	0·3	⁞	14·400		Telluric.	40 423	17	
	2nd edge,	0·3		14·470			40 440		13
	Stronger haze band—1st edge,	0·5	⁞⁞	14·505		Telluric.	40 453	7	
	2nd edge,	0·5		14·532			40 460		9
	Still stronger, but narrow haze band—								
	1st edge,	1·0	⁞⁞⁞	**14·565**	**40 464**	Telluric.	**40 469**	11	
	2nd edge,	1·0		**14·590**			**40 480**		

The above three bands constitute the **a band** in the high Sun spectrum. They are *there*, the most delicate trace imaginable, like three faint touches of water-colour laid on an engraving with a small crow-quill camel's-hair pencil. This **a band** is telluric of course, blackens exceedingly, terrifically, spreading at the same time redward, towards sunset, and in dry weather as much as wet. Its constituent or originating gas is not certainly known.

♄ June 22, 1878. Prisms = Nos. 6, 8, and 4. Dispersion = 28°. Re-arranged prisms for space C to D. Definition admirable. 10h. 30m. A.M. re-commenced with the **a band.**

Colour of the Continuous Spectrum at the Place.	Object observed, generally a black, fixed Fraunhofer Line.	Intensity of black. or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
Amber.	**a Band:** 1st and faintest portion—								
	1st side,	0·3	≡	8·714		Telluric.	40 427	7	
	2nd do.	0·3		8·737			40 434		12
	2nd and stronger—1st side,	0·7	≡	8·765		Telluric.	40 446	9	
	2nd do.	0·7		8·790			40 455		11
	3rd and strongest—1st side,	1·5	≣	**8·815**	**40 464**	Telluric.	**40 466**	8	
	2nd do.	1·5		**8·838**			**40 474**		38
	Sharp line,	2	∣	8·943			40 512		14
	Fine line suspected,	0·5	·	8·983			40 526		20
	Clear and sharp line,	2·5	∣	9·036	40 546	Iron.	40 546		26
	A graduated Solar group—								
	1st line, thin,	0·7	∣	9·100			40 572		14
	2nd line, double, A,	1	‖	9·147		Titanium.	40 586	7	
	Do. do. B,	1		9·160			40 593		9
	 3rd, strong,	2	∣	9·190		Titanium.	40 602		16
	4th, stronger,	2	∣	9·230		Iron.	40 618		9
	5th, stronger,	3	∣	9·262	40 625	Iron.	40 627		27
	Double line—1st faint,	1	∣ ‖	9·354			40 654	15	
	2nd stronger,	2·5	∣	9·374	40 669	Iron.	40 669		5
	Very faint double—1st component,	0·5	∣ ‖	9·417			40 674	13	
	2nd do.	0·5	∣	9·426			40 687		25
	Very faint but sharp single line,	1·	∣	9·483			40 712		14
	Very faint but sharp double—								
	1st component,	1·	∣ ‖	9·525			40 726	7	
	2nd do.	1	∣	9·545			40 733		32
	Strong double—1st line,	2	∣ ▌	9·635	40 772	Iron.	40 765	9	
	2nd line, stronger,	4	▌	9·667			40 774		25
	Suspected line,	0·7	·	9·735			40 799		21
	Do. do.	0·7	·	9·793			40 820		28
	Strong fine line,	2·	∣	9·873		Titanium.	40 848		15
	Very fine line,	1·	∣	9·918			40 863		9
	Fine line,	1·5	∣	9·945		Titanium.	40 872		11
Amber	Stronger fine line,	2·	∣	9·980		Iron.	40 883		54
	Very fine line,	1·	∣	10·132			40 937		29
	Fine line,	1.3	∣	10·215		Iron.	40 966		62
	Strongest line this morning, perhaps double,	**4·**	▌	**10·393**	**41 029**	Iron.	**41 028**		24
	Fine line,	1·	∣	10·459			41 052		13
	Suspected fine line,	0·5	∣	10·490			41 065		23
	Do. do.	0·5	∣	10·553			41 088		18
	Fine line,	1·	∣	10·610		Iron.	41 106		23
	Do.	1·	∣	10·670		Nickel.	41 129		11
	Do.	1·2	∣	10·704		Iron.	41 140		12
	Do.	1·	∣	10·745			41 152		16
	Do.	1·	∣	10·793			41 168		8

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Exquisitely fine close double—								
	1st component,	1·5	ǀ ǁ	10·813	41 177	Calcium.	41 176	2	
	2nd do.	1·5	ǀ	10·824			41 178		
	Very faint, wider double—								
	1st component,	0·7	ǀ ǀ ǀ	10·866			41 194	8	16
	2nd do.	0·7	ǀ	10·890			41 202		
Amber.	Fine line,	1·5	ǀ	10·923		?	41 213		11
	Strong clear line,	2·5	▌	10·951	41 223	Calcium.	41 226		13
	Very faint close double—								
	1st component,	0·5	ǀ ǁ	10·962			41 229	2	3
	2nd do.	0·5	ǀ	10·970			41 231		
	Fine line,	1·0	ǀ	11·030		Sodium.	41 250		19
	Stronger line,	2·	ǀ	11·080			41 268		18
	Clear line,	1·3	ǀ	11·093		Sodium.	41 272		4
	Do. do.	1·5	ǀ	11·145		Iron.	41 288		16
	Do. do.	1·	ǀ	11·198			41 306		18
	Strong line,	2·	ǀ	11·225		Iron.	41 316		10
	Very fine line,	1·0	ǀ	11·280			41 336		20
	Strong clear line,	3·	▌	11·352	41 360	Barium.	41 360		24
	Strong double: 1st and weaker,	1	ǀ ǀ ǀ	11·434	41 388	Iron.	41 388	8	28
	2nd and stronger,	2	ǀ	11·457	41 394	Iron.	41 396		
	Finest of lines,	0·5	ǀ	11·550			41 431		35
	Do. do.	0·7	ǀ	11·630		Titanium.	41 461		30
	Suspected line,	0·5	·	11·690			41 482		21
	Strong clear line,	2·5	▌	11·741		Calcium.	41 494		12
	Finest of lines,	1·	ǀ	11·795			41 513		19
	Fine line,	1·5	ǀ	11·855		Nickel.	41 534		21
	Very finest of lines,	0·8	·	11·954		Barium.	41 569		35
	Fine line,	1·2	ǀ	12·015		Nickel.	41 588		19
	Strong fine line; single in Angstrom; double here: 1st,	1·5	ǀ ǁ	12·110	41 624	Caicium.	41 621	3	33
	2nd,	1·5	ǀ	12·128			41 624		
	Very finest of lines,	0·7	·	12·245			41 668		44
	Do. do.	0·7	·	12·305			41 688		20
	Do. do.	0·5	ǀ	12·350			41 705		17
	Do. do.	0·6	·	12·393		Titanium.	41 719		14
	Do., and double: 1st component,	0·5	ǀ ǁ	12·465			41 740	5	21
	2nd do.,	0·5	ǀ	12·485			41 745		
	Suspected line,	0·3	·	12·515			41 753		8
	Fine line,	0·8	ǀ	12·555		Titanium.	41 764		11
	Suspected line,	0·5	·	12·574			41 772		8
	Fine line, double: 1st component,	0·8	ǀ ǀ ǀ	12·623			41 789	2	17
	2nd do., stronger,	1·5	ǀ	12·634	41 790	Iron.	41 791		
	Clear fine single line,	1·0	ǀ	12·890	41 880	Iron and Titanium.	41 880		89
	Suspicion of fine line,	0·5	·	12·942			41 896		16
	Fine clean line,	1·3	ǀ	13·083		Iron.	41 935		39
	Very fine line,	1·1	ǀ	13·385			42 018		83
Amber.	Fine and sharp,	1·	ǀ	13·708		Iron.	42 140		122
	Strong, fine, and sharp,	2·	ǀ	13·776	42 167	Iron.	42 165		25
	Do., do.	2·	ǀ	13·823			42 180		15
	Stronger and sharp,	3·	▌	13·864	42 185	Manganese.	42 188		8
	Fine line and sharp,	1·5	ǀ	13·932	42 198	Iron.	42 200		12
	Do. do.	1·	ǀ	13·998		Manganese.	42 225		25
	Very fine line,	0·5	ǀ	14·027		Manganese.	42 234		9
	Fine and close double, perhaps triple—								
	1st,	1·5	ǀ ǀǀ,	14·100		Manganese.	42 257	4	23
	2nd,	1·	ǀ	14·110			42 261	5	
	3rd, ?	0·3	,	14·124			42 266		
									34

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA. from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Fine line. This not in Angstrom, and his two adjacent Iron lines not here,	1·5	│	14·225		?	42 300		
	Very fine line,	1·	│	14·343			42 344		44
Amber.	Suspected fine line,	0·5	·	14·378		Telluric water vapour.	42 355		11
	Suspected line or lines,	0·5	·	14·457			42 382		27
	A fine line certain,	1·5	│	14·590		Iron.	42 430		48
	Do. do.	1·3	│	14·644		Iron.	42 448		18
	Do. do.	1·3	│	14·668		Iron.	42 454		6
	Do. do.	1·3	│ │	14·816	42 512	Iron.	42 510		56
	Do. do.	1·3	│ │	14·848			42 519		9
	Very finest of lines,	1·	│	15·008	42 571	Iron.	42 570		51
	Do. do.	1·	│	15·045		Titanium.	42 583		13
	Fine line,	1·5	│	15·235		?	42 653		70
	Do.	1·5	│	15·263	42 662	Titanium.	42 662		9
	Suspected line,	0·5	·	15·304		Telluric watery vap.	42 670		8
	Fine line, possibly double,	0·7	│	15·353			42 682		12
	Fine line,	0·5	·	15·384			42 690		8
	Fine clear double, 1st line,	1·4	│ │	15·440	42 699	Iron.	42 702	3	12
	2nd do.	2·0	│ │	15·455			42 705		
	Very faintest of lines,	0·5	·	15·485		Telluric watery vap.	42 715		10
	Do. do.	0·5	·	15·510			42 722		7
	Suspected thin band,	0·5	≡	15·546			42 732		10
	Fine line,	1·	│	15·600		Telluric watery vapour and chief "Rain-band" lines.	42 750		18
	Finest of lines,	0·7	│	15·618			42 753		3
	Do. do.	1·0	│	15·630			42 758		5
	Suspected fine line,	0·5	·	15·650			42 763		5
	Certain fine line,	1·3	│	15·778		Iron.	42 802		39
	Very fine line,	1·	│	15·840		Telluric watery vap.	42 822		20
	Fine line,	1·4	│	15·878		Iron.	42 831		9
	Fine line; space between this and last line shaded,	1·	│	15·924		Iron.	42 849		18
	Very fine line, probably double,	0·4	·	16·015			42 877		28
	Very fine line,	1·	│	16·048		Telluric water vapour.	42 888		11
Amber.	Very fine triple line, 1st palest,	0·5	│ │	16·108		Telluric water vapour.	42 906		18
	2nd line,	0·8	│ │	16·126			42 913	7	
	3rd darkest,	1·2	│ │	16·143			42 919	6	
	Finest possible line,	1·	│	16·190		Telluric water vapour.	42 934		15
	Do. do.	1·	│	16·214			42 942		8
	Strong line,	3·	┃	16·248	42 953	Iron.	42 952		10
	Finest of lines,	1·	│	16·274			42 960		8
	Excessively fine line, double?	0·7	‖	16·343		Telluric water vapour.	42 981		21
	Excessively fine line,	0·5	│	16·365			42 988		7
									12

AMBER colour ends here, and YELLOW begins.

The large number of excessively thin, and generally unimportant lines encountered hereabouts is probably due to faint traces of the rain-band lines, just visible, although the Sun is 70° high.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA. from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
Yellow.	Excessively thin band suspected,	0·6	≡	16·400			43 000		
	Certain fine line,	1·3	│	16·458		Iron.	43 016		16
	Thinnest and finest line,	1·	│	16·500			43 030		14
	Fine line,	1·	│	16·560		Telluric watery vap.	43 048		18
									9

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE DATA. from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
Yellow.	Very fine double: 1st component,	0·7	{ | || }	16·592			43·057	3	
	2nd do.	0·7		16·608			43·060		
	Fine line,	1·5	|	16·637		Titanium.	43 067		7
	Suspected fine,	0·3	·	16·658			43 072		5
	D¹ line; first side of it,	**10**	▌	**16·688**	**43 086**	Sodium.	**43 085**	3	13
	second side,			**16·697**			**43 088**		
	Very clear line and sharp,	3·	|	16·764		Nickel.	43 110		22
	Fainter line, but sharp,	1·	|	16·795		Telluric water vapour.	43 120		10
	D² line; first side of it,	**10**	▌	**16 830**	**43 130**	Sodium.	**43 130**	4	10
	second side,			**16 840**			**43 134**		
	Suspected faint line or band,	0·5	·	16·926			43 161		27
	Certain fine sharp line,	1·	|	16·976		Iron.	43 179		18
	Suspected fine line (reset prisms),	0·5	·	11·845			43 198		19
	Do. do.	0·5	·	11·870		Telluric water vapour.	43 208		10
	Suspected band,	0·7	≡	11·900			43 220		22
	Suspected fine line,	0·5	·	11·948		Telluric water vapour.	43 237		17
	Suspected band,	0·7	≡	11·985			43 251		14
	Suspected line,	0·5	·	12·010			43 260		9
	Suspicion of a line,	0·5	·	12·183			43 326		66
	Certain very fine line,	1·6	|	12·220		Iron.	43 338		12
	Suspicion of a line,	0·5	·	12·243		Iron.	43 344		6
	Fine line, clean and sharp,	1·5	|	12·327	43 368	Calcium.	43 368		24
	Suspicion of a band,	0·7	≡	12·360			43 380		12
	Fine line,	1·2	|	12·402			43 394		14
Yellow.	Strongest line hereabouts,	3·	▌	12·456	43 404	Barium.	43 405		11
	Excessively fine line,	1·0	|	12·486			43 416		11
	Very thin but wide double; 1st line,	1·0	{ | || }	12·543			43 432	11	16
	2nd line,	1·0		12·585			43 443		
	Excessively fine line, certain,	1·2	|	12·690			43 471		28
	Finest possible line,	0·7	|	13·075			43 573		102
	Strong fine line,	1·5	|	13·488	43 675	Iron.	43 675		102
	Thin faint band,	0·7	≡	13·517			43 682		7
	Very thin but certain fine line,	1·0	|	13·664		Iron.	43 724		42
	Do. do.	1·0	|	13·732			43 744		20
	Do. do.	1·0	|	13·763			43 750		6
	Beginning of band fading to right,	1·0	≡	13·797		Iron.	43 762		12
	Another band fading to right,	1·0	≡	13·946		Iron.	43 808		46
	Very fine line,	1·0	|	14·068			43 843		35
	Beginning of a faint band,	1·0	{ ≡ }	14·128		Iron.	43 860		17
	End of same, fading away,	0·1		14·133			43 862		2
	Line painfully thin,	0·6	|	14·208			43 882		20
	Do. do.	0·6	|	14·225			43 889		7
	Narrow band; beginning,	0·7	{ ≡ }	14·280			43 905	13	16
	end,	0·7		14·315			43 918		13
	Single very fine line,	1·	|	14·370		Copper.	43 931		16
	Very faint band,	0·3	≡	14·412		Barium.	43 947		43
	Fine line,	1·2	|	14·558		Iron.	43 990		
	Do.	1·	|	14·583			44 000		10
	Do.	1·	|	14·640			44 020		20
Yellow.	Suspicion of a line,	0·5	·	14·720			44 040		20
	Double, strong; 1st component,	3·	{ | || }	14·872	44 082	Iron.	44 082	6	42
	Do. 2nd	2·		14·890			44 088		

Observations end at 1h. 15m. P.M.

☾ June 24, 1878. Prisms 6, 8, and 4. Dispersion A to H = 28°. 10h. 15m. A.M.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA. from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
Yellow.	Last double repeated; 1st component,	3	{ ‖ }	11·759	{ 44 082	Iron.	{ 44 082	6	
	2nd,	2		11·774			{ 44 088		
	Suspicion of a line,	0·5	·	11·820			44 100		12
	Fine line,	1·0	|	11·918			44 128		28
	Stronger line,	2·0	|	11·970		Iron.	44 143		15
	Fine line,	1·0	|	11·993			44 151		8
	Fine line,	1·5	|	12·018			44 156		5
	Thin line,	1·2	|	12·050			44 165		9
	Faint band or group; beginning,	0·3	{ ≡ }	12·143			44 192	18	27
	end,	0·3		12·175			44 200		
	Thin line,	1·0	|	12·315			44 242		22
	Strong line,	2·	|	12·598	44 322	Iron.	44 322		80
	Fine line,	1·	|	12·730		?	44 363		41
	Stronger line,	1·5	|	12·974		Iron.	44 432		69
	Do. do.	1·4	|	13·043		Titanium and Iron.	44 451		19
	Fine line,	1·	|	13·065			44 458		7
	Faint, and perhaps double,	1·	‖	13·132			44 477		19
	Stronger line,	1·5	|	13·155		Iron.	44 481		4
	Strongest line hereabouts,	3·	|	13·202	44 496	Iron.	44 496		15
	Fine line,	1·3	|	13·233			44 502		6
	Double line; 1st component,	3·	{ ‖ }	13·298		Iron.	44 522	7	20
	2nd	1·5		13·318		?	44 529		
	Fine line,	0·8	|	13·365			44 543		14
	Strong line,	2·	|	13·430		Iron.	44 562		19
Yellow.	Faint line,	1·	|	13·533		?	44 586		24
	Fine line,	1·	|	13·614			44 609		23
	Do.	1·	|	13·645			44 614		5
	Do.	0·8	|	13·706			44 638		24
	Do.	1·	|	13·734		Titanium.	44 644		6
	Strongest line so far,	2	|	13·794		Sodium.	44 662		18
	Strong line,	1·4	|	13·845		Iron.	44 677		15
	Fine line,	1·2	|	13·902		?	44 693		16
	Strong, close double; 1st component,	3·	{ ‖ }	13·947	{ 44 707	Iron and	{ 44 704	6	11
	(Single in Angstrom); 2nd,	3·		13·961		Sodium.	{ 44 710		
	Fine line,	1·	|	14·052		Iron.	44 734		24
	Stronger line,	1·5	|	14·150		Titanium.	44 758		24
	Fine line (Not in Angstrom),	1·	|	14·323			44 803		45
	Do (Not in Angstrom),	1·	|	14·353			44 810		7
	Faint group; beginning,	0·5	{ ||| }	14·385			44 820	6	10
	end,	0·5		14·408			44 826		
	Fine line,	1·3	|	14·447		?	44 837		11
	Do.	1·3	|	14·488		?	44 848		11
	Perhaps a close double,	1·3	‖	14·530		Titanium.	44 860		12
	Triple line; 1st component,	3	{ ||| }	14·647	{ 44 893	Iron.	{ 44 890		30
	(1 & 2 single in Angst.) 2nd component,	2		14·655		Iron.	{ 44 892	2	
	3rd,	1		14·675		?	{ 44 898	6	
	Faint band; beginning,	1·5	{ ⁞ }	14·740		Iron.	44 916		18
	middle,	1		14·755			44 922	6	
	end,	0·5		14·790			44 931	9	
	Excessively fine line,	0·6	ı	14·865			44 950		19
	Do. do.	0·7	ı	14·903			44 962		12
	Do. do.	0·6	ı	15·013			44 995		33
									14

YELLOW Colour ends here: CITRON begins.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
CITRON.		1·5	ǀ	15·062		Titanium.	45 009		
	Band of lines—beginning,	2·	} ǀǀǀ {	15·125		Iron.	45 027		18
	end,	0·3		15·187		?	45 043	16	
	Sharp line,	2·	ǀ	15·229		Iron.	45 056		13
	Hazy line,	1·3	⋮	15·265			45 066		10
	Fine line,	1·	ǀ	15·315			45 080		14
	Sharp line,	1·5	ǀ	15·372		Iron.	45 097		17
	Strong double line : 1st component,	3	▌ } ▌▌ {	15·653	45 167	Iron ?	45 167		70
	2nd component, (Stronger of the two in Angstrom)	2	▌	15·677		Iron.	45 173	6	
	Fine line,	0·7	ǀ	15·764			45 197		24
	Do.	0·7	ǀ	15·785			45 202		5
	Do.	0·7	ǀ	15·805			45 207		5
	Strong double line ; 1st component, (Faint and single in Angstrom)	2·	▌ } ▌▌ {	15·832			45 216		9
	2nd component,	2·	▌	15·873			45 227	11	
	Band (a single excessively strong line in Angstrom)—								11
	begins with a double line,	1·5	ǁ } ǁ≡	15·918	45 238	Iron.	45 238		
	suspicion of a line,	1·0	:	15·930			45 240	2	
	end of band,	0·3	.	15·950			45 248	8	
	Strong and sharp line,	3·	▌	16·308	45 341	Iron and calcium.	45 340		92
	Strong line,	1·3	ǀ	16·360		Calcium.	45 351		11
	Fine line,	0·8	ǀ	16·403			45 363		12
	Strong line,	1·	ǀ	16·453	45 376	Iron and calcium.	45 376		13
	Suspicion of a line,	0·3	·	16·490			45 387		11
	Sharp line,	1·	ǀ	16·575	45 409	Calcium.	45 408		21
	Faint and hazy line,	0·6	.	16·607			45 416		8
	Strong line,	1·3	ǀ	16·650		Iron.	45 425		9
	Sharp line,	1·2	ǀ	16·715		Calcium.	45 443		18
	Very strong and sharp,	3·	▌	16·757	45 455	Calcium.	45 454		11

At 11h. A.M. shortened focus of collimator, readjusted prisms, and used blue glass, and silver-on-glass mirror, in place of the usual quick-silvered glass, as a temporary experiment. The image of the Sun thereby was exquisitely single, and optically good, but the *lines* in the spectroscope were not better, perhaps not so good, which I attributed chiefly to the silver-on-glass mirror being rather smaller than the other.

CITRON.	Strong sharp line repeated,	3	▌	8·196	45 455	Calcium.	45 455		
	Fine line,	1	ǀ	8·222			45 462		7
	Strong line,	2	▌	8·257	45 473	Iron.	45 471		9
	Finer line,	1	ǀ	8·312		Iron.	45 487		16
	Fine line,	1	ǀ	8·357			45 500		13
	Strong line,	2·5	▌	8·395		Calcium.	45 512		12
	Fine line,	1·3	ǀ	8·500		Iron.	45 538		26
	Decided line,	2	▌	8·580		Iron.	45 560		22
	Strongest line hereabouts,	**4**	▌	**8·667**	**45 586**	Iron.	**45 582**		22
	Strong line,	3	▌	8·760	45 611	Iron.	45 609		27
	Fine line,	1	ǀ	8·825			45 627		18
	Strong line,	2	▌	8·868		Titanium.	45 640		13
	Double line, strong : 1st component,	2	▌ } ▌▌ {	8·925		?	45 659		19
	2nd do.	2	▌	8·950		Iron.	45 667	8	
	Decided line,	1·3	ǀ	9·022			45 689		22
	Clear line,	1·3	ǀ	9·080			45 708		19
	Strong line,	3	▌	9·175	45 728	Iron.	45 730		22
	Fine line,	1	ǀ	9·208			45 741		11
	Faint band,	0·5	≡	9·418			45 800		59
	Double line : 1st component,	1·5	ǀ } ǀǀ {	9·500	45 820	?	45 820		20
	2nd do.	1·5	ǀ	9·533	45 825	Iron.	45 830	10	
	Strong ! line (but only a fine line, 1st component of a very faint double, in Angstrom),	3	▌	9·750		?	45 893		63
									7

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Fine line, ...	1	|	9·774			45 900		18
	Do.	1	|	9·838		Iron.	45 918		34
	Strong line and clear, . . .	3	|	9·955	45 951	Magnesium.	45 952		
	Last line repeated after new focussing.								
CITRON.	Strong line and clear, . . .	3	|	9·983	45 951	Magnesium.	45 952		14
	Strong line, ...	2	|	10·030		Iron.	45 966		10
	Do.	2	|	10·073			45 976		26
	Do.	2	|	10·170			46 002		19
	Fine line, ...	1	|	10·256		Barium.	46 021		24
	Do.	1	|	10·344			46 045		21
	Do.	1	|	10·425		Titanium.	46 066		14
	Strong double line : 1st component, .	3	| { ‖ }	10·470	46 083	Titanium.	{ 46 080	6	
	2nd do. .	3		10·493			{ 46 086		17
	Fine line, ...	1	|	10·557			46 103		16
	Do.	1	|	10·608			46 119		15
	Strong line, ...	3	|	10·658		?	46 134		8
	Fine line (very faint in Angstrom), .	2	|	10·687		?	46 142		14
	Very fine line, ...	1	|	10·778			46 166		10
	Strong sharp line, ...	3	|	10·819	46 174	Iron.	46 176		37
	Do. do.	3	|	10·937	46 214	Iron.	46 213		34
	Faint band, ...	1	≡	11·055			46 247		32
	Very faint band, ...	0·5	≡	11·160			46 279		22
	(A Titanium line at Wave-number-place 46 290 in Angstrom not here),								
	Unequal double : stronger member, .	2	| { ‖ }	11·233			46 301	8	
	(Not in Angstrom) : fainter, . .	1		11·257			46 309		39
	Fine line, ...	1	|	11·387		Titanium.	46 348		18
	Fine double : 1st component, . .	1·5	| { ‖ }	11·448			46 366	6	
	2nd do. . .	1·5		11·465		Nickel.	46 372		23
	Fine line, ...	1	|	11·543			46 395		6
	Do.	1	|	11·565			46 401		7
	Close triple line : 1st component, .	2·0	| { ||| }	11·594		Titanium.	46 408	5	
	2nd do. .	2·0		11·604		?	46 413	2	
	3rd do. .	2·0		11·613		?	46 415		18
	Fine line, ...	1	|	11 685		Titanium.	46 433		12
	Do.	1	|	11·723			46 445		19
	Fine double line : 1st component, .	1	| { ‖ }	11·792		Iron.	46 464	2	
	(Single in Angstrom and thin), 2nd do.	1		11·802			46 466		26
	Unequal double line : 1st weaker, .	1	| { ‖ }	11·897		?	46 492	5	
	2nd stronger, .	2		11·922	46 497	Iron.	46 497		19
	Very close double or multiple line, .	1	‖	12·018			46 516		46
	Distinct strong line, . .	**4**	|	**12·262**	**46 562**	Iron.	**46 562**		74
	Close double : 1st component, . .	1·5	| { ‖ }	12·555	46 636	Iron and	46 636	3	
	(Much stronger in Angst.), 2nd do. .	1·5		12·565		Titanium.	46 639		13
CITRON.	Strong line, ...	2	|	12·623	46 651	Iron.	46 652		33
	Fine line, ...	1	|	12·736			46 685		43
	Faintest band, beginning, . .	0·3	{ ≡ }	12·890			46 728	5	
	end, . . .	0·3		12·907			46 733		13
	Strong line, ...	3	|	12·958		Iron.	46 746		11
	Fine double : 1st component, . .	1	| { ‖ }	13·000			46 757	3	
	2nd do. . .	1		13·010			46 760		24
	Very strong line, . . .	**4**	|	**13·104**	**46 785**	Iron.	**46 784**		47
	Strong line, preceded by faint band, .	3	≡|	13·305	46 831	Iron.	46 831		29
	Fine line and clear, ...	2	|	13·408			46 860		12
	Do. do.	2	|	13·440		Titanium.	46 872		14

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Fine line,	1	|	13·490			46 886		
CITRON.	Do.	1	|	13·555			46 900		14
	Strong line,	2	|	13·615		Iron.	46 914		14
	Faintest band,	0·5	⁝	13·674			46 926		12
	Strong double: 1st component,	2·5	| } ‖ }	13·753	46 952	Iron.	46 949	9	23
	2nd do.	2·5	| } ‖ }	13·790		Chromium.	46 958		
	Fine line,	1	|	13·810			46 966		8
	Do.	1	|	13·866			46 978		12
	Very strong double— 1st component,	**4**	| } ‖ }	**13·925**	**46 993**	Iron.	**46 992**	16	14
	2nd do.	**4**	| } ‖ }	**13·980**	**47 007**	Iron.	**47 008**		
	Citron colour ends here. Green colour begins here.								
GREEN.	Strong line,	2	|	14·100		Iron.	47 038		30
	Very fine line,	0·5	|	14·130		Iron.	47 045		7
	Fine line,	1	|	14·176			47 056		11
	Very strong line,	**4**	|	**14·217**		Iron.	**47 063**		7
	Fine line,	1·	|	14·305		Iron.	47 086		23
	Strong line,	2·	|	14·360		Iron.	47 099		13
	Do.	2·	|	14·425		Iron.	47 113		14
	Fine line,	1·	|	14·455			47 122		9
	Clear line,	1·5	|	14·495		Iron.	47 132		10
	A single, solitary line,	3	|	14·710	47 183	Iron.	47 183		51
	Fine line,	1	|	14·778		Titanium.	47 202		19
	Do.	1	|	14·840		Iron.	47 221		19
	Do.	1	|	14·907			47 236		15
	Fine line,	1	|	15·030			47 271		35
	Very strong line,	3	|	15·107	47 291	Iron.	47 290		19
	Close double line: 1st component,	1·5	| } ‖ }	15·158	47 305	Iron.	47 302	4	12
	2nd do.	1·5	| } ‖ }	15·170			47 306		
	Single line,	2·	|	15·250		Iron.	47 326		20
	Faint double line: 1st component,	1·	| } ‖ }	15·327		Iron.	47 345	7	19
	2nd do.	1·	| } ‖ }	15·345		?	47 352		
	Strong line,	2	|	15·422		Iron.	47 370		18
	Fine line,	1	|	15·465			47 381		11
	Then ensues a markedly blank portion of spectrum.								
	Clear line,	2	|	15·762	47 450	Cobalt.	47 450		69
	Hazy line,	2	⁝	15·893		Calcium.	47 484		34
	Sharp line,	2	|	15·940			47 497		13
	Do.	2	|	16·020		?	47 520		23
	Faint band: 1st side,	1	⁝	16·105		Cobalt.	47 543	5	23
	2nd do.	1		16·122			47 548		
	Clear double: 1st component,	2	| } ‖ }	16·193	47 571	Iron.	47 567	13	19
	2nd do.	2	| } ‖ }	16·243			47 580		
	Fine line,	1	|	16·325		Titanium.	47 597		17
	Do.	1	|	16·363			47 607		10
	Do.	1	|	16·430			47 623		16
	Strong line,	2	|	16·510		Iron.	47 641		18
	Fine line,	1	|	16·557			47 650		9
	Do.	1	|	16·610			47 663		13
	Do.	1	|	16·640			47 669		6
	Strong double line: 1st component,	3	| } ‖ }	16·668	47 674	Iron.	47 676	5	7
	2nd do.	3	| } ‖ }	16·683	47 680	Iron.	47 681		

1h. 10m. P.M. Sun cut off by stove-pipe. Mem.—Focus-tube of collimator is now pushed close in; and focus-tube of telescope is in middle of its range.

♂ June 25, 1878. Prisms 6, 8, and 4: Dispersion = 28°.
10h. 30m. A.M.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Very strong double line—								
	1st component, .	**4**	▌⎫ ▌▌⎧	**8·485**	**47 674**	Iron.	**47 674**	4	
	2nd do. .	**4**	▌⎭ ▌▌⎩	**8·496**	**47 680**	Iron.	**47 678**		
	Exquisitely fine double line—								
	1st component, . .	1	ǀ⎫ ǁ⎧	8·564			⎧ 47 693	7	15
	2nd do. . ,	1	ǀ⎭ ⎩	8·595			⎩ 47 700		
	Strong line, ...	3	▌	8·643	47 710	Iron.	47 710		10
	Fine double line: 1st component, .	1	ǀ⎫ ǁ⎧	8·716			⎧ 47 729	8	19
	2nd do. .	1	ǀ⎭ ⎩	8·748			⎩ 47 737		
	Strong line, the 1474 Kirchoff, or the Solar Corona, line, in conjunction with an Iron line, ...	3·5	▌	8·910	47 778	Iron and Helium?	47 779		42
	Fine line, ...	1	ǀ	8·970			47 793		14
	Do.	1	ǀ	9·020			47 805		12
	Do.	1	ǀ	9·040			47 810		5
	Very fine line, ...	0·7	ǀ	9·123			47 829		19
	Clear line, ...	1·2	ǀ	9·207			47 850		21
	Strong line, ...	3	▌	9·253		Iron.	47 860		10
	Fine line, ...	1	ǀ	9·304			47 873		13
	Do.	1	ǀ	9·367			47 887		14
	Strong line, ...	3	▌	9·447		Iron.	47 906		19
	Clear line, ...	2	ǀ	9·504			47 920		14
	Group—								
	1st is double or treble and hazy,	3	⎫ ⎧	9·608	⎫	⎧	47 944	7	24
	2nd, single and sharp, . .	2	⎬ ⋮▌⋮ǀǀ ⎨	9·640	⎬ 47 951	Titanium. ⎨	47 951	7	
	3rd, do. do. . .	2	⎭ ⎩	9·667	⎭	⎩	47 958		
	Fine line, ...	1	ǀ	9·718			47 973		15
	Do.	1	ǀ	9·765			47 985		12
GREEN.	Do.	1	ǀ	9·814		Copper.	47 997		12
	Clear line, ...	2	ǀ	9·967		Iron.	48 036		39
	Band of fine lines followed by a strong line—								
	1st component, ...	1	ǀ⎫	10·086			48 068		32
	2nd do.	1·5	ǀ⎬ ǀǀǀ▌	10·105			48 073		5
	3rd do.	2	ǀ⎬	10·128			48 078		5
	4th do. and chief, .	3	▌⎭	10·144	48 081	Iron.	48 082		4
	Clear line, ...	2	ǀ	10·214		Iron.	48 097		15
	Fine double line: 1st component, .	1	ǀ⎫ ǀǀ⎧	10·275		Cobalt. ⎧	48 108	3	11
	2nd do. .	1	ǀ⎭ ⎩	10·292		⎩	48 111		
	Strong double line: 1st component, .	3	ǀ⎫ ǁ⎧	10·445	⎫ 48 146	Unknown. ⎧	48 142	6	31
	2nd do. .	3	ǀ⎭ ⎩	10·480	⎭	⎩	48 148		
	Clear line, ...	2	ǀ	10·556		Iron.	48 170		22
	The Great E line—								
	1st component, .	**6**	▌⎫ ▌▌⎧	**10·675**	**48 199**	Calcium and Iron.	**48 200**	10	30
	2nd do. .	**8**	▌⎭ ⎩	**10·707**	**48 209**	Iron.	**48 210**		
	Haze follows above, Fine line, . .	1	ǀ	10·750		Cobalt.	48 220		10
	Second pair of E lines—								
	1st component, .	**4·8**	▌⎫ ▌▌⎧	**10·817**	**48 234**	Iron & Cobalt.	**48 234**	5	14
	2nd do. .	**4·8**	▌⎭ ⎩	**10·855**	**48 239**	Calcium.	**48 239**		
	Third pair of E lines: 1st component,	3·7	ǀ⎫ ⎧	10·918	48 245	Calcium. ⎧	48 247	3	8
	(Not in Angstr.) fine intercalated line,	0·5	ǀ⎬ ǀıǀ ⎬	10·932		⎬	48 250	6	
	2nd component,	3·7	ǀ⎭ ⎩	10·954	48 256	Iron. ⎩	48 256		
	Last pair of E lines: 1st component, .	2·5	ǀ⎫ ǁ⎧	10·995		Calcium. ⎧	48 265	4	9
	2nd do. .	2·5	ǀ⎭ ⎩	11·013		Calcium. ⎩	48 269		
	Very fine line, ...	0·5	ǀ	11·055			48 279		10
									25

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed, Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data, from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Fine line, ...	1·5	│	11·160			48 304		
	Do.	1	│	11·200			48 313		9
	Do.	1	│	11·255			48 327		14
	Strong line, ...	3	┃	11·288		Manganese.	48 334		7
	Fine line, ...	2	│	11·347		Iron.	48 348		14
	Do.	2	│	11·404		Iron.	48 363		15
	Fine double line : 1st component, .	1	│ } ‖ }	11·465		Iron.	{ 48 377		14
	2nd do. .	1	│	11·483			{ 48 382	5	
	Very fine line, ...	1	│	11·533			48 394		12
	Strong double line : 1st component, .	2	┃ } ‖ }	11·594		Iron.	{ 48 408		14
	(This pair faint in Angstrom), 2nd do.	2	┃	11·624		?	{ 48 415	7	
	Fine double line : 1st component, .	1	│ } ‖ }	11·744		Iron.	{ 48 443		28
	2nd do. .	1	│	11·754			{ 48 446	3	
	Sharp and single line, ...	3	┃	11·795			48 456		10
		2	┃	11·900			48 481		25
	11h. 30m. A.M.								
	Single line, ...	1·5	│	11·997			48 504		23
	Very fine line, ...	1	│	12·032			48 513		9
	Clear double line : 1st component, .	2	│ } ‖ }	12·068		Cobalt.	{ 48 520		7
	2nd do. .	2	│	12·104		Manganese.	{ 48 529	9	
	Strong hazy line, ...	3	┇	12·172	48 545	Iron.	48 546		17
	Strong line, ...	2	┃	12·303		Iron.	48 571		25
	Fine line, ...	1	│	12·372			48 586		15
GREEN.	Strong double or treble— 1st component, .	3	┃ } ‖ }	12·426	{ 48 597	Iron.	{ 48 595		9
	(Single in Angstrom), 2nd do. .	3	┃	12·440			{ 48 598	3	
	Fine line, ...	1	│	12·480		Titanium.	48 608		10
	Very fine line, ...	0·7	│	12·505		Titanium.	48 613		5
	Fine line and clear, ...	1·2	│	12·540			48 622		9
	Thicker line (not in Angstrom), .	1·5	┃	12·622			48 640		18
	Faint band, ...	0·5	≡	12·710			48 661		21
	Very faint band, ...	0·3	≡	12·730			48 667		6
	Faint hazy line, ...	1·	┇	12·797		Copper.	48 683		16
	Stronger line, ...	1·5	│	12·827		Iron.	48 687		4
	Faint line, ...	1·	│	12·868		Iron.	48 697		10
	Stronger line, ...	1·3	│	12·920		Iron.	48 709		12
	Faint line, ...	0·8	│	13·110		Titanium.	48 754		45
	Strong line, ...	3·	┃	13·192	48 773	Chromium and Iron.	48 773		19
	Reset Telescope.								
	Last line repeated, ...	3	┃	5·468	48 773	Chromium and Iron.	48 773		
	Sharp line, ...	1·5	│	5·565	48 794	Chromium.	48 794		21
	Do.	2·	│	5·632	48 808	Chromium and Iron.	48 808		14
	Do.	2·	│	5·724	48 828	Iron.	48 828		20
	Fine line, ...	1	│	5·803			48 844		16
	Triple line : 1st component, . .	2	│ } │││ }	5·867			48 859		15
	2nd do. . .	0·5	╎	5·902			48 868	9	
	3rd do. . .	2	│	5·914		Iron.	48 870	2	
	Band of most exquisitely graduated lines, clean and sharp, and ending with a strong line— 1st component, .	0·5	· } ╷││┃	5·926			48 873		3
	2nd do. .	1·0	╷	5·940		Manganese.	48 875		2
	3rd do. .	1·5	│	5·973		Manganese.	48 883		8
	4th do. .	2·	│	6·000		Manganese.	48 888		5
	5th and chief.	**4·**	┃	**6·022**		Iron.	**48 893**		5
									17

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								Breadths & Doubles.	Distances.
	Fine line,	0·8	ǀ	6·100			48 910		
	Sharp double line: 1st component,	1·5	ǀǀ	6·128		Iron.	48 917		7
	2nd do.	1·5	ǀǀ	6·167		Iron.	48 925	8	
	Sharp but unequal pair: 1st component	3	❙ǀ	6·283		Calcium.	48 952		27
	2nd do.	1·5	❙ǀ	6·312		Titanium.	48 958	6	
	Sharp fine line,	1	ǀ	6·410		Iron.	48 979		21
	b^1 line, little more than cloud—								
	1st edge of its nebulosity,	0·5	⋮	6·485			48 996		17
	1st edge of its line, faint but thick,	**7**	⋮❙⋮	**6·507**	**49 004**	Magnesium	**49 002**	6	
	2nd edge of said line,	**7**	⋮❙⋮	**6·528**			**49 005**	3	
	2nd edge of the nebulosity,	0·5	⋮	6·556			49 011	6	
	Sharp fine line,	1	ǀ	6·604			49 022		11
	Sharp stronger line,	1·5	ǀ	6·659		Iron.	49 035		13
	Sharp line,	0·8	ǀ	6·712			49 047		12
	Do.	1·	ǀ	6·780			49 064		17
	Do.	1·	ǀ	6·814		Nickel.	49 072		8
	Sharp fine line,	0·7	ǀ	6·928			49 097		25
	b^2 line, cloudy exceedingly—								
	1st edge of its nebulosity,	0·5	⋮	6·945			49 102		5
	1st edge of its line, faint but thick,	**6**	⋮❙⋮	**6·966**	**49 107**	Magnesium	**49 106**	4	
	2nd edge of do.	**6**	⋮❙⋮	**6·982**			**49 110**	4	
	2nd edge of nebulosity,	0·5	⋮	7·000			49 114	4	
	Line of blacker matter (not so in Angstrom),	3	❙	7·018		Iron.	49 118		4
	Fine line,	1	ǀ	7·047			49 124		6
GREEN.	**b^3, strong clear line,**	**5**	❙	**7·127**	**49 142**	Iron and Nickel.	**49 142**		18
	b^4, hazy, broad, and faint— 1st edge,	**4**	⋮❙⋮	**7·188**	**49 159**	Magnesium	**49 158**		16
	2nd do.	**4**	⋮❙⋮	**7.214**			**49 163**	5	
	Sharp line,	1·2	ǀ	7·247		Iron.	49 171		8
	Do.	1·	ǀ	7·287		Iron.	49 180		9
	Very fine line,	0·5	ǀ	7·323			49 188		8
	Strong line,	2	ǀ	7·430	49 210	Iron.	49 212		24
	Fine line,	1	ǀ	7·573		Iron.	49 233		21
	Very fine line,	0·5	ǀ	7·670			49 262		29
	Strong line (very faint in Angstrom),	1·3	ǀ	7·716		Nickel.	49 270		8
	Fine line,	1·	ǀ	7·743		Sodium.	49 277		7
	Double line: 1st component,	1·4	ǀǀ	7·792		?	49 288		11
	2nd do.	1·4	ǀǀ	7·830		Sodium.	49 296	8	
	Double line: 1st component,	1·5	ǀǀ	7·885		Iron.	49 307		11
	2nd do.	1·5	ǀǀ	7·924		Iron.	49 315	8	
	Strong line,	2	ǀ	8·038		Iron.	49 340		25
	Very fine line,	0·8	·	8·116		Nickel.	49 356		16
	Very thin double: 1st component,	0·6	ǀǀ	8·177			49 370		14
	2nd do.	0·6	ǀǀ	8·190			49 373	3	
	Strong close double: 1st component,	2·5	ǀǀ	8·273			49 391		18
	2nd do.	2·5	ǀǀ	8·285			49 393	2	
	Fine line,	1	ǀ	8·332		Nickel.	49 404		11
	Strong hazy line,	3	⋮❙⋮	8·440	49 426	Iron.	49 426		22
	Re-focussed Telescope.								
	Same hazy line,	3	⋮❙⋮	8·460			49 426		
	Sharp double line: 1st component,	1	ǀǀ	8·558	49 438	Nickel.	49 440		14
	2nd do.	1	ǀǀ	8·574			49 443	3	
	Fine line,	0·7	ǀ	8·635			49 457		14 19

olour of the Continuous pectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Strong line,	2	┃	8·724		Iron.	49 476		
	Very fine line,	0·5	╷	8·780			49 488		12
	Fine line,	1	│	8·823		Iron.	49 498		10
	Hazy line,	1	:│:	8·920		Titanium.	49 518		20
	Sharp line,	1	│	8·998		Iron.	49 534		16
	Fine line,	0·7	│	9·059			49 547		13
	Strong line,	1·5	┃	9·103		Iron.	49 557		10
	Fine line,	0·7	│	9·117		Iron.	49 559		2
	Strong line,	1·5	┃	9·167		Iron.	49 570		11
	Fine line,	0·8	┃	9·195			49 576		6
	Do.	1	│	9·264		Iron.	49 590		14
	Do.	0·7	╷	9·322		Titanium.	49 603		13
	Do.	1	│	9·557	49 650	Nickel.	49 653		50
	Double line: 1st component,	1·5	│ ││	9·793		Iron.	49 706	10	53
	2nd do.	1·5	│	9·832		?	49 716		
	Strong line, hazy,	2	:┃:	9·920	49 734	Iron.	49 733		17
	Great change of focus in the spectrum hereabouts; the telescope focusses now close to one end of its tube range.								
	Last line repeated, with new focus,	2	:┃:	10·067	49 734	Iron.	49 734		
	Fine line,	1	│	10·164		Copper.	49 756		22
	Do.	1	│	10·233			49 768		12
	Do.	1	│	10·300			49 782		14
	Do.	1	│	10·406			49 803		21
REEN.	Strong line,	2	┃	10·450	49 813	Nickel.	49 812		9
	Finer line,	1·3	│	10·480			49 818		6
	Strong line,	3	┃	10·517	49 820	Iron.	49 823		5
	Fine line,	1	│	10·572			49 835		12
	Stronger line,	2	┃	10·600		Iron.	49 840		5
	Fine line,	1	│	10·717			49 863		23
	Do.	1	│	10·810			49 883		20
	Do.	1	│	10·834			49 889		6
	Strong line,	3	┃	10·893	49 898	Iron.	49 898		9
	Ultra faint band, begins faintly,	0·3	▤	10·964			49 912	9	14
	ends sharply,	1		11·008			49 921		
	Very faint double line—								
	1st component,	0·7	│ ‖	11·054			49 931	2	10
	2nd do.	0·7	│	11·068			49 933		
	Fine line,	1	│	11·140			49 936		3
	Strong and sharp double line—								
	1st component,	3	┃ ┃┃	11·215		?	49 963	9	27
	2nd do.	3	┃	11·255		Iron.	49 972		
	Fine line,	1	│	11·303			49 981		9
	Strong and sharp line,	2	┃	11·373	50 004	Nickel and Iron.	49 994		13
	Sharp line,	1·5	│	11·404			50 000		6
	Do.	1·5	│	11·445			50 008		8
	Close double line: 1st component,	1	│ ‖	11·472			50 013	3	5
	2nd do.	1	│	11·486			50 016		
	GREEN colour ends here, and GLAUCOUS colour begins.								
	Strong line,	2	┃	11·620		Iron ?	50 042		26
	Fine line,	1	╷	11·668			50 053		11
	Very strong line (not so strong in Angstrom),	3	┃	11·704		Iron.	50 059		6
	Unequal double line: 1st component,	1	│ │┃	11·800		Iron.	50 077	6	18
	2nd ,,	2	┃	11·832			50 083		
	Strong line,	2	┃	11·983		Iron.	50 112		29
aucous.	Fine line,	1	╷	12·068		Iron.	50 129		17
	Unequal double line: 1st component,	2	│ ‖	12·188	50 152	Iron and Titanium.	50 151	1	22
	2nd do.	1	╷	12·190			50 152		

1h. 15m. P.M., Stove-pipe cuts off Sun.

10h. 30m. A.M., ☿ June 26, 1878.

Bad definition. Set and re-set the prisms several times for this part of the spectrum, but without improving the definition. Removed the blue glass, and again adjusted prisms for space between E and F. At 11h. A.M., found definition good.

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Glaucous.	Last double line repeated—								
	1st component, .	2		7·380	50 152	Iron and	50 150		
	2nd do. .	1		7·398		Titanium.	50 154	4	
	Suspected hazy line, ...			7·534			50 186		32
	Strong line, . Blank region in Angstrom.	2		7·605		Iron.	50 201		15
	Fine line, .	1		7·687			50 220		19
	Do. .	1		7·755			50 237		17
	Do. .	1		7·780			50 242		5
	Strong line, .	2		7·834			50 254		12
	Fine line, .	1		7·877			50 263		9
	Do. .	1		7·916			50 273		10
	Fine line, ...	1		7·945			50 280		7
	Very strong double line—								
	1st component,	3		7·970		Iron.	50 286		6
	2nd do.	3		8·050		Iron.	50 303	17	
	A group of fine lines—								
	Probably a water-vapour group, said to be strong in summer and in a low Sun. 1st component,	1		8·090		Iron and	50 312		9
	2nd do.	1		8·105		perhaps	50 317	5	
	3rd do.	1		8·125		Tell. water-	50 319	2	
	4th do.	1		8·134		vap. group.	50 322	3	
	Fine line, ...	1		8·252			50 350		28
	Strong line, ...	2		8·300		Iron.	50 362		12
	A triplet: 1st and faintest, . .	1		8·383			50 381		19
	2nd strong, . . .	3		8·396	50 382	Calcium.	50 383	2	
	3rd do. . . .	3		8·434	50 393	Iron.	50 392	9	
	An even triplet—								
	Probably a Telluric water-vapour group. 1st component,	2		8·489		Probably a	50 403		11
	2nd do.	2		8·523		Tell. water-	50 411	8	
	3rd do.	2		8·567		vap. group.	50 420	9	
	An inclined triplet: 1st and smallest,	1		8·654		Titanium.	50 440		20
	2nd and middle,	2		8·675		Titanium.	50 444	4	
	3rd and strongest,	3		8·705		Nickel.	50 450	6	
	Fine line, ...	1		8·895			50 490		40
	Do.	1		8·957			50 503		13
	A triplet: 1st component, . .	1		9·020			50 518		15
	2nd do. . .	1		9·028			50 519	1	
	3rd do. strongest,	3		9·060		Iron.	50 527	8	
	Re-focussed.								
	Last, or 3rd of triplet, repeated, .	3		9·083		Iron.	50 527		
	Fine line, ...	1		9·156			50 543		16
	Stronger line, ...	1·5		9·190			50 550		7
	A faint and uneven triplet—								
	1st component, .	0·7		9·283			50 572		22
	2nd do. .	1·0		9·313		Iron.	50 578	6	
	3rd do. .	0·7		9·340			50 584	6	
	Fine line, ...	0·8		9·425			50 603		19
	A strong but uneven double—								
	1st component, .	2		9·504	50 620	Unknown.	50 621		18
	2nd do. .	1		9·540		Nickel.	50 628	7	
	Fine line, ...	1		9·613			50 643		15
	Strong double line: 1st component, .	2		9·670		Iron and	50 655		12
	2nd do. .	2		9·698		Titanium.	50 660	5	
	Group of fine lines: 1st component, .	1		9·713			50 664		4
	2nd do. .	1		9·724			50 667	3	
	3rd do. .	1		9·732			50 668	1	
	4th do. .	1		9·744			50 670	2	11

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	Strong line, ...	3	┃	9·800	50 681	Iron.	50 681		
	Fine line, ...	1	│	9·848			50 694		13
	Sharp side of a faint band, . .	1	≣	9·883			50 702		8
	Vanishing side of do. . . .	0·2		9·928			50 713	11	
	Strong line, ...	2	┃	10·008		Iron and Titanium.	50 734		21
	Strong double : 1st component, .	2	┃ ‖	10·060	50 748	Iron.	50 747		13
	2nd do. .	2	┃	10·083			50 751	4	
	Faint haze from last line ends here, .	0·2	≣	10·170			50 770		19
	Fine line, ...	1	│	10·224		Iron.	50 780		10
	Strong line, ...	1·5	┃	10·278			50 791		11
	Very fine line, ...	0·5	│	10·307			50 797		6
	Fine line, ...	1·	│	10·350			50 806		9
	Fine double line : 1st component, .	1·	│ ‖	10·389		Titanium.	50 813		7
	2nd do. .	1·	│	10·406			50 817	4	
	Very fine line, ...	0·4	│	10·457			50 828		11
	Fine line, ...	1	│	10·522			50 842		14
	Do.	1	│	10·589			50 855		13
	Faint band of lines : 1st and strongest,	2·	│	10·660		Iron.	50 870		15
	2nd strongest, .	1·	│	10·680		?	50 873	3	
	3rd do. .	0·7	│	10·690		?	50 876	3	
	4th and weakest,	0·5	·	10·710		?	50 879	3	
	Strong line, ...	2	┃	10·798		Iron.	50 896		17
	Do.	1·5	┃	10·898		Iron.	50 917		21
	Fine line, ...	1	│	10·950			50 928		11
	Strong line or lines, ...	2	┃ or ‖	11·070		Iron.	50 951		23
	Do. do.	2	┃ or ‖	11·124	50 963	Nickel, Sodium, and Titanium.	50 963		12
	Fine line, ...	1	│	11·160			50 969		6
Glaucous.	Haze between last line and this one, .	2	⋮	11·200		Nickel, Sodium, and Titanium.	50 976		7
	Fine line, ...	1	│	11·243			50 982		6
	Strong line, ...	2	┃	11·317		Nickel, Sodium, and Titanium.	50 994		12
	Do.	2	┃	11·400		Nickel, Sodium, and Titanium.	51 008		14
	Fine line, ...	1	│	11·462		Iron.	51 017		9
	Do.	1	│	11·532			51 028		11
	Do.	1	│	11·578			51 035		7
	Do.	1	│	11·620			51 042		7
	Strong line, ...	2	┃	11·687		?	51 053		11
	Fine line, ...	1	│	11·778			51 068		15
	Triplet of fine lines : 1st component,	1	│ ⦀	11·810			51 073		5
	2nd do. .	1	│	11·820			51 075	2	
	3rd do. .	1	│	11·840		Iron.	51 078	3	
	Fine double line : 1st component, .	1	│ ‖	11·895		Iron.	51 087		9
	2nd do. .	1	│	11·936			51 094	7	
	Strong line, ...	2	┃	12·028		Iron.	51 109		15
	Fine line, ...	1·5	│	12·088		Iron.	51 118		9
	Very fine line, ...	1	│	12·207			51 137		19
	These three lines were apparently omitted by accident, and are taken from a subsequent re-examination of the spectrum, ...	4	┃			Iron.	**51 153**		
		1	·			Iron.	51 165		
		2	│			Iron.	51 190		
	"Little c;" a very strong but hazy line (strong and clear line in Angstrom), ...	**4**	┇	**12·470**	**51 242**	Iron.	**51 242**		105

The telescope's focus about here is very troublesome. When the above thick iron line is seen *single*, the small one is seen sharp at focussing-tube's 15th division; but at the 25th they are blurred; and at the 35th they become sharp again, but with the thick iron line notably doubled by bad focus.

Reset all the prisms for F.

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								Breadths & Doubles.	Distances.
	"Little c," line repeated, hazy and strong: 1st side, .	**4**	▮	**9·345**	**51 242**	Iron.	**51 238**	7	
	(Strong and clear line in Angstrom)— 2nd side, .			**9·380**			**51 245**		
	Fine line, ...	1	ǀ	9·510		Iron.	51 273		28
	Do.	1	ǀ	9·585		Iron.	51 288		15
	Do.	1	ǀ	9·610		Iron.	51 293		5
	Do.	1	ǀ	9·732		Iron.	51 318		25
	Strong double line: 1st component, .	2	ǀ ǀ ‖	9·905		Iron.	51 353	7	35
	2nd do. .	2		9·944		?	51 360		
	Faint and unequal double line— 1st component, .	1	ǀ ǀ ǀ ǀ	10·086		Iron.	51 392	6	32
	2nd do. .	0·5		10·118			51 398		
Glaucous.	A doubly graduated group of lines— 1st component, .	0·5	ǀ ǀ ǀ ǀ ǀ ǀǀǀǀǀ	10·220		Iron and ?	51 420		22
	2nd do. .	1·0		10·245			51 426	6	
	3rd do. .	1·2		10·260			51 429	3	
	4th do. .	1·0		10·297			51 436	7	
	5th do. .	0·5		10·342			51 446	10	
	Fine line, ...	1	¦	10·425		Nickel.	51 463		17
	Strong double line: 1st component, .	3	ǀ ǀ ‖	10·516	51 485	Barium and Iron.	51 482	8	19
	2nd do. .	3		10·555			51 490		

More trouble with the focus of telescope. Changed silver-on-glass mirror, re-adjusted prisms, but found no benefit to the faulty definition. Tried simple glass magnifier for quartz eye-piece, but still no benefit; for still, best focus for a thick line is not the best focus for a thin one; and there seem to be two foci, about 0·7 inch apart on the telescope focus-tube!

The present amount of Dispersion by prisms 6, 8, and 4 = 28° from A to H; and though found very suitable in the red and yellow, may be too much in the green and blue, which we are now working in; we shall therefore now try prisms 6 and 8 alone, with Dispersion from A to H = 21°.

Thursday, June 27, 1878.
9h. 30m. A.M.

Colour of the Continuous Spectrum at the Place.	Object observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Breadths & Doubles.	Distances.
	Last double line repeated— 1st component, .	3	ǀ ǀ ‖	8·923	51 485	Barium and Iron.	51 480	10	
	2nd do. .	3		8·956			51 490		
	Fine line, ...	1	ǀ	9·006			51 503		13
	Strong line, ...	2	▮	9·074		Iron.	51 520		17
	Faint resolvable band: 1st component,	1	ǀ ǀ ǀ ǀǀǀ	9·165			51 543		23
	2nd do. .	1		9·180			51 548	5	
	3rd do. .	1		9·204			51 554	6	
	Fine line, ...	1·	ǀ	9·265			51 570		16
	Stronger line, ...	1·5	ǀ	9·302			51 579		9
	Strong thick line, ...	3·	▮	9·336		Iron.	51 587		8
	Fine line, ...	1·	ǀ	9·408			51 606		19
Glaucous.	Strong double line: 1st component, .	3	ǀ ǀ ‖	9·485	51 629	Iron.	51 628	16	22
	2nd do. .	3		9·565	51 644		51 644		
	Re-set the Prisms.								
	Last double line repeated— 1st component, .	3	ǀ ǀ ǀ	9·555	51 629	Iron.	51 629	15	
	2nd do. .	3		9·616	51 644		51 644		
	Hazy line, ...	1·5	⋮	9·645		Nickel.	51 650		6
	Fine line, ...	1·5	ǀ	9·696			51 663		13
	Faint hazy band: beginning, . .	0·7	≣	9·813			51 694	6	31
	end, . . .			9·840			51 700		
	Fine line, ...	1	ǀ	9·904			51 718		18
	Do.	1	ǀ	9·920			51 721		3
	Strong double: 1st component, .	2	ǀ ǀ ‖	9·955		Iron.	51 730	3	9
	2nd do.	2		9·960			51 733		7

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Fine line, ...	1	│	9·993			51 740		
	Do.	1	│	10·060		Iron.	51 758		18
	Very fine line, ...	0·5	╷	10·104			51 769		11
	Fine line, ...	1	│	10·167			51 786		17
	Strong and sharp double line—								
	1st component, .	2	│ } ││ }	10·193		?	51 793	13	7
	2nd do. .	2	│ } ││ }	10·242		Iron.	51 806		
	Fine line, ...	1	│	10·357			51 835		29
	Strong line, ...	2	┃	10·388		Barium.	51 843		8
	Do.	2	┃	10·535			51 881		38
Glaucous.	Very fine line, ...	0·7	╷	10·545			51 883		2
	Fine line, ...	1	│	10·646			51 908		25
	Do.	1·5	│	10·678			51 917		9
	Very strong double: 1st component,	3	█ } ██ }	10·738	51·932	Iron.	51 932	8	15
	2nd do.	3	█ } ██ }	10·772	51·940	Iron.	51 940		
	Clear double line: 1st component, .	1·5	│ } ││ }	10·835		?	51 957	5	17
	2nd do. .	1·5	│ } ││ }	10·855		Iron.	51 962		
	Wide double line: 1st component, .	1·	│ } │ │ }	10·913		Iron.	51 978	7	16
	2nd do. .	1·	│ } │ │ }	10·946		Iron.	51 985		
	10h. 30m. A.M., white cirri and cirrostrati cover all the sky.								
	Band of fine lines: 1st component, .	1	│ } ││││ }	10·965			51 990	4	5
	(Not in Angstrom), 2nd do. .	1	│	10·978			51 994	3	
	3rd do. .	1	│	10·990			51 997	4	
	4th do. .	1	│	11·004		Titanium.	52 001		
	Strong sharp line, ...	2	┃	11·060	52·021	Iron.	52 015	15	14
	Do. do.	2	┃	11·117			52 030		
	Do. do.	3	┃	11·288	52·075	Calcium.	52 075		45
	Fine line, ...	1	│	11·357			52 093		18
	Do.	1	│	11·382			52 098		5
	Do.	1	│	11·398			52 102		4
	Hazy fine line, ...	1	⁞┃⁞	11·425			52 109		7
	Strong line (not in Angstrom; probably by error of engraving), .	2	┃	11·498		Nickel.	52 127		18
	Very strong double line—								
	1st component, .	3	█ } ██ }	11·554	52·140	Iron.	52 141	8	14
	2nd do. .	3	█ } ██ }	11·590	52·148	Iron.	52 149		
laucous.	Fine line, ...	1	│	11·610			52 155		6
	do.	1	│	11·640			52 163		8
	Very fine line, ...	0·5	╷	11·667			52 170		7
	Fine line, ...	1	│	11·720		Cobalt.	52 183		13
	Do.	1	│	11·738			52 187		4
	Sharp line, ...	1·5	│	11·796		Nickel.	52 203		16
	Fine line, ...	1	│	11·825			52 211		8
	Do.	1	│	11·860		Iron.	52 220		9
	Very fine line, ...	0·7	╷	11·876			52 224		4
	Strong line, ...	2	┃	11·905			52 232		8
	Haze begins, ...	0·5	⁞█⁞	11·977			52 248		16
	The Great F line: 1st side,	**10**	} ⁞█⁞ }	**11·990**	**52·254**	Hydrogen	**52 252**	2	4
	2nd do.	**10**		**12·010**			**52 254**		
	Its haze ends, ...	0·5		12·032			52 260		6
	Sharp and black line, ...	3	█	12 064	52·265	Iron.	52 267		7
	Faint haze, ...	0·5	≣	12·095			52 274		7
	Hazy line, ...	1·5	⁞┃⁞	12·160			52 292		18
	Hazy group: 1st component, . .	1	│ } ⁞┃⁞ {	12·216			52 306	6	14
	2nd and chief compt. .	3	│	12·240	52·312	Nickel.	52 312	7	
	3rd component, . .	1	╷	12·267			52 319		
									6

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Faint haze band,	0·5	≡	12·304			52 325		
	Double line: 1st component,	1	│ } ║ {	12·370			52 346	12	21
	2nd component,	1	│	12·420			52 358		
	Fine line,	1	│	12·515		Calcium.	52 382		24
	Do.	1	│	12·542			52 389		7
	Sharp strong line (*not* in Angstrom's map),	**4**	┃	**12·570**			**52 397**		8
	Fine line,	1	│	12·610			52 406		9
	Do.	1	│	12·687			52 426		20
	Fine line,	1	│	12·747		Iron.	52 441		15
	Do.	1	│	12·786			52 451		10
	Do.	1	│	12·805			52 456		5
	Very fine line,	0·8	·	12·837			52 463		7
	Strong and sharp line, } Very faint triplet here in Angstr.	2	│	12·878			52 474		11
	Do. do.	2	│	12·905		Cobalt.	52 482		8
	Do. do.	2	│	12·935			52 488		6
	Strong line,	1·5	│	12·975			52 499		11
	Very fine double line: 1st component,	0·6	· } ‖ {	13·080		Iron. }	52 525	2	26
	2nd do.	0·6	·	13·088			52 527		
	Fine line,	1	│	13·147			52 543		16
	Clear line,	1·5	│	13·224		Iron.	52 560		17
	Fine line,	1	│	13·296		Nickel.	52 578		18
	Strong double line: 1st component,	2	│ } {	13·380	} 52 600	Nickel. }	52 598	4	20
	(Single in Angstr.) 2nd do.	2	│	13·393		Nickel.	52 602		
	Strong line,	1·3	│	13·460			52 619		17
	Fine line,	1	│	13·497			52 629		10
Glaucous.	Hazy line,	1	⁞│⁞	13·564			52 646		17
	Strong, unequal double line— 1st component,	2	│ { ║ {	13·614 }	**52 664**	Manganese. }	52 658	6	12
	(Single in Angstr.) } **2nd and greater do.**	**4**	┃	**13·638**			**52 664**		
	Fine line,	1	│	13·678			52 674		10
	Fine line,	1	│	13·744			52 690		16
	Do.	1	│	13·776			52 696		6
	Do.	1	│	13·823			52 707		11
	Strong line,	2	│	13·884		?	52 720		13
	Very fine line,	0·7	·	13·965			52 737		17
	Do. do.	0·7	·	13·990			52 743		6
	Fine line,	1·	│	14·030			52 750		7
	Stronger line,	1·5	│	14·068			52 759		9
	Fine line,	1·3	│	14·080			52 763		4
	Do.	1·	│	14·131			52 776		3
	Strong line,	2	│	14·204		Calcium.	52 795		19
	Fine line,	1	│	14·286			52 816		21
	Stronger line,	1·3	│	14·333			52 827		11
	Fine line,	1·	│	14·375			52 838		11
	Strong line,	2	│	14·460		Titanium.	52 860		22
	Fine line,	1	│	14·560		Iron.	52 887		27
	Faint double line: 1st component,	1	│ } ‖ {	14·655		Iron. }	52 911	2	24
	2nd do.	1	│	14·661			52 913		
	Faint double line: 1st component,	1	│ } ‖ {	14·693		}	52 921	3	8
	2nd do.	1	│	14·708			52 924		
	Faint hazy line,	1	⁞:⁞	14·755		Iron.	52 937		13
	Fine line,	1	│	14·855			52 962		25
	Hazy line,	1·3	⁞│⁞	15·027	53 005	Cobalt.	53 005		43
	Fine line,	1	│	15·077			53 018		13
									18

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	Group of sharp lines: 1st component,	1	│	15·146			53 036		
	2nd do.	1	│	15·160			53 039	3	
	3rd & strongest,	2	│	15·185		Iron.	53 046	7	
	Fine line,	1	│	15·235			53 058		12
	Hazy band: beginning,	1	⁞	15·287		Nickel.	53 070		12
	end,	0·3	⁞	15·305		Nickel.	53 076	6	
	Very strong and sharp line,	**4**	┃	**15·446**	**53 109**	Manganese.	**53 109**		33
	Fine line,	1	│	15·604		Cobalt.	53 147		38
	Do.	1	│	15·636			53 154		7
	Hazy band: beginning,	1	⁞	15·773			53 188		34
	end,	0·3	⁞	15·797			53 199	11	
	Strong sharp line,	3	┃	15·938		Iron.	53 226		27
	Line hazy to right,	2	│⁞	15·990			53 238		12
	Fine line,	1	│	16·070			53 256		18
	Stronger line,	1·5	│	16·140		Iron.	53 272		16
	Fine line,	1	│	16·223			53 293		21
	Double line: 1st component,	1	│	16·256			53 300		7
	2nd do.	1	│	16·280			53 306	6	
	Clear line,	1·5	│	16·357			53 323		17
	Strong line,	3	┃	16·424	53 342	Manganese.	53 342		19
	Fine line,	1	│	16·472		Manganese.	53 354		12
	Very fine line,	0·5	╷	16·490			53 358		4
	Fine line,	1·3	│	16·573		Titanium.	53 377		19
	Very fine line,	0·5	╷	16·628		Titanium.	53 390		13
	Fine line,	1	│	16·660			53 397		7
	Group of lines: 1st component,	1·3	│	16·702		Nickel.	53 407		10
	2nd do.	1	│	16·728		Nickel.	53 412	5	
Glaucous.	3rd do.	1	│	16·737			53 415	3	
	Very fine line,	0·5	╷	16·786			53 426		11
	Notable and strong line,	**4**	┃	**16·820**	**53 433**	Manganese.	**53 433**		7
	Faint double line: 1st component,	1	│	16·898			53 452		19
	2nd do.	1	│	16·915			53 456	4	
	Fine line,	1	│	16·952			53 464		8
	Faint hazy and perhaps double line,	1	⁞	17·017			53 479		15
	Very fine line (strong in Angstrom),	0·7	╷	17·096		?	53 498		19
	Clear line,	1·5	│	17·205		Iron.	53 524		26
	Fine line,	1·3	│	17·275			53 541		17
	Finer line,	0·8	╷	17·353		Titanium.	53 559		18
	Triple group: 1st component,	2	┃	17·415		Iron.	53 573		14
	2nd do.	1	│	17·443		?	53 580	7	
	3rd do.	2	┃	17·475		?	53 587	7	
	Fine line,	1	│	17·538			53 602		15
	Triple group: 1st component,	1	│	17·617			53 620		18
	2nd and chief,	3	┃	17·650		Iron.	53 628	8	
	3rd component,	1	│	17·690			53 638	10	
	Clear line,	1·5	│	17·810		Titanium.	53 666		28
	Fine line,	0·8	╷	17·858			53 677		11
	Do.	1·	│	17·906		Iron.	53 688		11
	Do.	1·	│	17·945			53 697		9
	Do.	1·	│	17·980		Manganese.	53 705		8
	Clear line,	1·5	│	18·050		?	53 722		17
	Strong line,	2	┃	18·104		Iron.	53 735		13
	Fine line,	1	│	18·163			53 748		13
	Very fine line,	0·7	╷	18·258			53 771		23
	Do.	0·4	╷	18·304			53 782		11
									12

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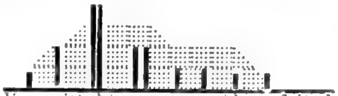
	Strong double line: 1st component,	2		18·358		Zinc.	53 794	14	
	2nd do.	2		18·413		?	53 808		15
	Very fine line,	0·4		18·480			53 823		17
	Wide double line: 1st component,	1		18·550			53 840	10	
	2nd do.	1		18·592			53 850		19
	Fine line,	1		18·675			53 869		16
	Very strong line and hazy,	**4**		**18·748**	**53 885**	Nickel.	**53 885**		27
	Haze extends thus far,	0·3		18·865			53 912		21
	Group of lines: 1st component,	2		18·970		Titanium.	53 933	8	
	2nd do.	0·5		19·002			53 941	7	
	3rd do.	2		19·034		Manganese.	53 948	11	
	4th do.	0·5		19·084			53 959	9	
	5th do.	2		19·122		Iron.	53 968		9
	Fine line,	1		19·164			53 977		13
	Do.	1		19·235		Magnesium.	53 990		17
	Do.	1		19·304			54 007		6
	Strongest line hereabouts,	**4**		**19·340**	**54 013**	Unknown.	**54 013**		5
	Fine line,	1		19·360			54 018		5
	Do.	1		19·382			54 023		10
	Hazy line,	1		19·430			54 033		11
	Sharp line,	2		19·478		Titanium.	54 044		13
	Do.	1·3		19·526			54 057		6
	Double line: 1st component,	1·5		19·555			54 063	3	
	2nd do.	1·5		19·570			54 066		23
	Very fine line,	0·8		19·667			54 089		18
	Fine line sharp,	1·5		19·743			54 107		10
Glaucous.	Hazy line,	1·5		19·790			54 117		13
	Do.	1		19·850			54 130		14
	Strong line (from 54 050 to 54 240, all is vacant in Angstrom, excepting this line),	3		19·915		Titanium.	54 144		14
	Perhaps double line,	1·5		19·978			54 158		7
	Fine line,	1		20·000			54 165		14
	Hazy line,	1		20·062			54 179		13
	Sharp line,	1		20·117			54 192		12
	Sharp line,	1·5		20·174			54 204		12
	Rather hazy group: 1st component,	2		20·221			54 216	11	
	2nd do.	1		20·265			54 227	12	
	3rd do.	2		20·320		Titanium.	54 239		15
	Hazy band,	0·5		20·390			54 254		20
	Do.	0·5		20·470			54 274		13
	Group of lines: 1st component,	1		20·530			54 287	3	
	2nd do.	3		20·547		Zinc.	54 290	10	
	3rd do.	2		20·587		Iron.	54 300		7
	Fine line,	0·8		20·615			54 307		40
	Hazy band,	0·5		20·783			54 347		11
	Sharp double line: 1st component,	2		20·833		Iron.	54 358	10	
	2nd do.	2		20·878		?	54 368		12
	Fine line,	1		20·930			54 380		12
	Sharp double line: 1st component,	2		20·982			54 392	12	
	2nd do.	2		20·039			54 404		8

Then follows a group containing within it, amongst other finer lines, one very strong line, a notable haze at the same time enveloping them all, in this manner and degree—



. The whole group is sensibly different from Angstrom's Map, though fully coinciding with his apparent idea of its being the first of "the hazy ones," a new class of lines which seem to characterise the violet end of the spectrum. The places of the lines or linelets in this particular group are thus—

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								Breadths & Doubles.	Distances.
	A group to be called "the first of the hazy ones"—								
	1st component, ...	0·5	'	21·073			54 412		
	2nd do.	1·5	|	21·100			54 418		6
	3rd and principal, .	**5**	❘	**21·134**	**54 420**	Titanium.	**54 421**		3
Glaucous.	4th, a close double, . .	1·5	|	21·160	54 430	Titanium.	54 431		10
	5th component, . . .	1	|	21·172			54 434		3
	6th do. . . .	1	|	21·185			54 438		4
	7th do. . . .	1	|	21·205			54 442		4
	8th do. . . .	0·8	|	21·216			54 444		2
	9th do. . . .	0·7	|	21·266			54 456		12
									11
	1h. 10m. P.M.								
	Friday, 28th June 1878. Prisms 8 and 6. Dispersion = 21°.								
	The principal line of last group, for reference place only, ...	**5**	⁞❘⁞	**8·365**	**54 420**	Titanium.	**54 423**		
	A notable double line: 1st component,	2·5	| } ‖ }	8·545		}	54 467	6	
	2nd do.	2·5	|	8·567			54 473		
	Clear line, ...	1·5	|	8·624			54 490		17
	Do.	1·5	|	8·656			54 497		7
	Fine line, ...	1	|	8·691			54 507		10
	Do.	1	|	8·728			54 516		9
	Do.	1	|	8·780			54 530		14
	Sharp double line, but with haze behind—								16
	1st component, .	2	⁞❘⁞ } ⁞❘⁞❘⁞	8·840		}	54 546	10	
	2nd do. .	2	⁞❘⁞	8·882			54 556		
	Strong and sharp line, .	**4**	❘	**8·955**	**54 576**	Iron and Chromium.	**54 577**		21
	Sharp double line: 1st component, .	2	| } ‖ }	9·066		? }	54 608	11	31
	2nd do.	2	|	9·104		Copper.	54 619		
	A group: 1st component, ...	3	❘ } ǀǀǀǀǀ {	9·224		Chromium. {	54 650		31
	2nd do. . . .	1	|	9·255			54 659	9	
	3rd do. . . .	3	❘	9·284			54 667	8	
	4th do. . . .	1	|	9·320			54 676	9	
	5th do. . . .	3	❘	9·353			54 684	8	
Glaucous.	Faint haze, ...	1	⁞	9·385			54 692		8
	Faint hazy line, ...	1	⁞|⁞	9·423			54 702		10
	Do. do.	1	⁞|⁞	9·453			54 710		8
	Strong line, ...	3	❘	9·480		Iron.	54 718		8
	Faint hazy line, ...	0·5	⁞|⁞	9·594			54 747		29
	Do. do.	0·5	⁞|⁞	9·635			54 758		11
	Do. do.	0·5	⁞|⁞	9·655			54 762		4
	Do. do.	0·5	⁞|⁞	9·676			54 768		6
	Strong double line: 1st component, .	2	| } ‖ }	9·730		Iron. }	54 781	8	13
	2nd do. .	2	|	9·757			54 789		
	Strong line, ...	2	|	9·831			54 808		19
	Fine line, ...	1	|	9·874			54 819		11
	Strong line, ...	2	|	9·916			54 830		11
	Stronger line, ...	3	❘	9·967	54 842	Iron.	54 843		13
	Strong double line: 1st component, .	2	| } ‖ }	10·095		Titanium. }	54 874	8	31
	2nd do. .	2	|	10·130			54 882		
	Very fine line, ...	0·5	'	10·226			54 904		22
	Strong double line: 1st component, .	2	| } ‖ }	10·285		Iron. }	54 918	14	14
	2nd do. .	2	|	10·340			54 932		
	Quadruple group of fine lines—								
	1st component, .	0·6	| } ǀǀǀ {	10·430		{	54 952		20
	2nd do. .	0·6	|	10·455			54 959	7	
	3rd do. .	0·6	|	10·477			54 963	4	
	4th do. .	0·6	|	10·495			54 968	5	
									12

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								Breadths & Doubles.	Distances.
	Group of strong lines: 1st component,	2·5	▌ ❘❘❘	10·565			54 980		
Glaucous.	2nd do. .	2	❘	10·623	54 996	Iron and Titanium.	54 997	17	
	3rd do. .	2	❘	10·645			55 003	6	
	GLAUCOUS colour ends here; and BLUE colour begins.								
	Triple group: 1st component, .	2	▌ ❘❘❘	10·720			55 018		15
	2nd do. .	1	❘	10·755			55 027	9	
	3rd do. .	2	▌	10·768			55 031	4	
	Faint hazy line, ...	1	⁞	10·790			55 036		5
	Do. do.	1	⁞	10·867			55 054		18
	Very strong and wide double line— 1st component, .	3	▌ ▌▌	10·905	55 063	Unknown.	55 064		10
	2nd do. .	3	▌	10·996	55 087	Iron.	55 087	23	
	Hazy or double line, . . .	1	⁞	11·175		Calcium.	55 129		42
	Graduated triple—								
	1st and smallest component, .	0·7	❘ ❘❘❘	11·240			55 145		16
	2nd and mean do. .	1·	❘	11·263			55 150	5	
	3rd and strongest do. ,	1·5	❘	11·298			55 159	9	
	Strong line, ...	2·5	▌	11·410		Iron.	55 186		27
	Clear line, ...	1·	❘	11·458			55 197		11
	Quadruple group of fine lines—								
	1st component, .	1	❘ ❘❘❘❘	11·516			55 211		14
	2nd do. .	1	❘	11·533			55 215	4	
	3rd do. .	1	❘	11·553			55 220	5	
	4th do. .	1	❘	11·570			55 222	2	
	Triple group of lines—								
	1st component, .	1	❘ ❘▌❘	11·642			55 240		18
	2nd and chief do. .	2·5	▌	11·665		?	55 246	6	
	3rd do. .	1	❘	11·676			55 248	2	
BLUE.	Double line: 1st component, . .	1·5	❘ ❘❘	11·750		?	55 266		18
	2nd do. . .	1·5	❘	11·778			55 272	6	
	Fine line, ...	1	❘	11·792			55 276		4
	11h. A.M.								
	Strong line (not in Angstrom), . .	3	▌	11·904			55 302		26
	Fine line, ...	1	❘	11·925			55 307		5
	Strong clear line, ...	3	▌	11·977	55 316	Iron.	55 319		12
	Very fine line, ...	1	❘	12·012			55 328		9
	Strong line, ...	2	▌	12·050			55 336		8
	Clear line, ...	1·5	❘	12·143			55 358		22
	Fine line, ...	1	❘	12·200			55 372		14
	Group of strong clear lines— 1st component, .	2	▌ ❘▌❘	12·248		Manganese.	55 383		11
	2nd do. .	3	▌	12·262			55 387	4	
	3rd do. .	2	▌	12·270			55 389	2	
	Strong line, ...	2	▌	12·317		Calcium.	55 400		11
	Stronger line, ...	3	▌	12·367			55 411		11
	Very fine line, ...	0·5	❘	12·423			55 426		15
	Very strong line, ...	**4**	▌	**12.504**	**55 448**	Calcium.	**55 446**		20
	Hazy band, ...	1	⁞	12·574			55 462		16
	Strong line, ...	2	▌	12·655		Calcium.	55 480		18
	Fine line, ...	1	❘	12·736			55 498		18
	Do.	1	❘	12·774			55 507		9
	Fine double line: 1st component, .	1	❘ ‖	12·846			55 522		15
	2nd do. .	1	❘	12·875			55 529	7	
	Very strong double line— 1st component, .	**4**	▌ ▌▌	**12·990**	**55 558**	Titanium.	**55 555**		26
	2nd do. .	**4**	▌	**13·035**			**55 564**	9	16

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								Breadths & Doubles.	Distances.
	Fine line,	1	│	13·107			55 580		
	Hazy band: 1st side,	2	≡	13·150			55 591		11
	2nd do.	2		13·180			55 598	7	
	Hazy band,	1	≡	13·272			55 618		20
	Triple group of lines: 1st component,	2	│││	13·338			55 633		15
	2nd do.	1		13·373	55 642	Unknown.	55 642	9	
	3rd do.	2		13·430		Titanium.	55 651	9	
	Fine line,	1	│	13·635			55 704		53
	Do.	1	│	13·705			55 720		16
	Strong line, shaded to right,	2·5	┃≡	13·845		Titanium.	55 753		33
	Strong sharp line,	3	┃	13·948		Barium.	55 778		25
	Strong line,	2	┃	14·042		Titanium.	55 800		22
	Fine line,	1	│	14·135			55 820		20
	Very strong line,	**4**	┃	**14·191**	**55 835**	Titanium.	**55 834**		14
	Fine line,	1	│	14·228			55 842		8
	Do.	1	│	14·280			55 854		12
	Strong line,	2	┃	14·332		Iron.	55 866		12
	Fine line,	1	│	14·386			55 877		11
	Do.	1	│	14·428			55 887		10
	Strong line,	2	┃	14·470			55 897		10
	Haze band: 1st side,	1	≡	14·495			55 902		5
	2nd do.			14·510			55 906	4	
	Group of graduated lines—								
	1st component,	1	│┃┃	14·585		Titanium.	55 922		16
	2nd do.	2		14·628			55 932	10	
	3rd and strongest,	3		14·683			55 944	12	
BLUE.	Very fine line,	0·7	│	14·733			55 956		12
	Do.	0·7	│	14·790			55 968		12
	Very strong double line—								
	1st component,	3	┃┃	14·932	56 000	Titanium.	56 000		32
	2nd do.	3		14·945		Calcium.	56 002	2	
	Fine line,	1	│	14·993		Calcium.	56 013		11
	Strong double line: 1st component,	2	││	15·035	56 027	Iron.	56 022		9
	(Single in Angstrom), 2nd do.	2		15·085			56 036	14	
	Fine line,	1	│	15·170			56 055		19
	Hazy band: 1st side,	1	≡	15·187		Cobalt.	56 060		5
	2nd do.	1		15·224			56 069	9	
	Fine line,	1	│	15·283			56 082		13
	Very black line,	3	┃	15·332	56 094	Iron.	56 094		12
	11h. 55m.								
	A band of lines: 1st component,	1	│┃┃│	15·393			56 108		14
	2nd do.	2		15·428		Titanium.	56 116	8	
	3rd and chief,	3		15·455			56 122	6	
	4th and last,	2		15·476			56 126	4	
	Strong hazy line,	2	⁞┃⁞	15·543		Barium.	56 140		14
	Stronger and hazy line,	3	⁞┃⁞	15·672	56 167	Titanium.	56 167		27
	Fine line,	1	│	15·825			56 203		36
	Broad faint haze band: 1st side,	0·6	≡	15·908		Titanium.	56 221		18
	2nd do.	0·6		15·977			56 236	15	
	Wide double line: 1st component,	2	┃┃	16·075			56 258		22
	2nd do.	2		16·130	56 270		56 270	12	
	Last pair repeated: 1st component,	2	││	7·780		?	56 258		
	(Very faint in Angstrom, 2nd do.	2		7·835	56 270		56 270	12	
	Fine line,	1	│	7·905			56 286		16
	Do.	1	│	7·950			56 297		11
	Do.	1·2	│	7·973			56 302		5
									41

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								Breadths & Doubles.	Distances.
	Strong line (very faint double in Angstrom),	3	▌	8·150		?	56 343		
	Fine line,	1	|	8·342			56 389		46
	Do.	1	|	8·385		Manganese.	56 399		10
	Do.	1·5	|	8·487			56 422		23
	Strong line, hazy on either side,	3	⁞|⁞	8·548	56 436	Titanium.	56 436		14
	A narrow band,	2	≡	8·665		Manganese.	56 466		30
	Fine line,	1	|	8·724			56 479		13
	Strong line,	2	|	8·780		Titanium.	56 492		13
	Fine line,	1	|	8·818		Chromium.	56 501		9
	Do.	1	|	8·854			56 509		8
	Very strong line, "little d," with two following lines and haze (these latter particulars not in Angstrom)—								
	1st component,	**5**	▌	**8·904**	**56 522**	Iron.	**56 521**		12
	2nd do.	3	▌	8·926			56 526	5	
	3rd do.	1	|	8·948			56 529	3	
	Band of fine lines, perhaps double ones, backed by haze—								
	1st component,	0·5	|	9·030			56 547		18
	2nd do.	1	|	9·068			56 555	8	
	3rd do.	2	|	9·103		Manganese.	56 563	8	
	4th do.	3	▌	9·150		Manganese and Iron.	56 573	10	
	(The whole system very imperfect in Angstr.) 5th do.	2	|	9·195			56 582	9	
	Fine line,	1·5	|	9·240			56 591		9
BLUE.	Strong hazy line (not in Angstrom),	2	▒	9·398			56 602		11
	Strong hazy line,	2	▒	9·487		Iron.	56 642		
	Clear line, preceding,	2	|	9·572	56 663	Iron.	56 659		17
	Very strong and black line, following,	**4**	▌	**9·600**			**56 665**	6	
	Narrow haze band,	1	≡	9·652			56 676		11
	Broad and fainter haze band—								
	1st side,	0·5	≡	9·720		Magnesium.	56 692		16
	2nd do.	0·5	≡	9·760			56 701	9	
	Very strong line,	3	▌	9·937		Iron.	56 741		40
	Faint haze,	0·5	⁞	10·020			56 760		19
	Clear line,	2	|	10·122		Manganese.	56 784		24
	Hazy line,	1	▒	10·195			56 800		16
	Do.	1	▒	10·260			56 817		17
	Strong double line: 1st component,	3	▌	10·322	56 834	Iron and Titanium.	56 830		13
	2nd do.	3	▌	10·365			56 840	10	
	Strong hazy line,	3	▒	10·490			56 870		30
	Do do.	3	▒	10·610		Manganese.	56 898		28
	Hazy band almost resolved into lines—								
	1st side,	0·5	≡	10·727		Manganese.	56 924		26
	2nd do.	2	≡	10·792			56 940	16	
	Clear line,	2	|	10·852		Manganese.	56 953		13
	Strong line,	**4**	▌	**10·907**		Iron.	**56 966**		13
	Clear line,	2	|	10·950		Manganese.	56 976		10
	Do.	2	|	10·994		Manganese.	56 987		11
	Fine line,	1	|	11·020			56 992		5
	Do.	1	|	11·042			56 997		5
	BLUE colour ends here ; INDIGO begins.								
	Very thin line,	1	|	11·065			57 002		5
INDIGO.	Stouter line,	2	|	11·095			57 009		7
	Strong hazy line: 1st side,	**4**	▒	**11·143**	**57 025**	Manganese. Titanium. Calcium.	**57 020**		11
	2nd do.	**4**	▒	**11·181**			**57 031**	11	17

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	Hazy line,	1	⁞┃⁞	11·264			57 048		
	Do.	1	⁞┃⁞	11·354		Manganese.	57 068		20
	Strong hazy line,	2	⁞┃⁞	11·420		Titanium.	57 081		13
	Hazy line,	1	⁞┃⁞	11·507			57 100		19
	Strong line,	3	┃	11·583		Iron.	57 116		16
	Faint hazy line,	1	⁞⁞	11·635		Titanium.	57 127		11
	Exquisite bands of beautifully graduated lines follow, thus :—								
	Very fine line,	0·5	·	11·730			57 148		21
	Fine line, haze intervenes.	0·8	|	11·750			57 151	3	
	Fine line, haze intervenes.	1·2	|	11·770			57 154	3	
	Clear line, stronger haze intervenes.	2	┃	11·798		Titanium.	57 161	7	
	Strong line, stronger haze intervenes.	3	┃	11·849		Iron.	57 172	11	
	Strongest line, strong haze intervenes.	**5**	┃	**11·886**		Iron.	**57 180**	8	
	Strong line, weak haze intervenes.	3	┃	11·915		Iron ?	57 188	8	
	Fine line,	1	|	11·940			57 192	4	
	Very faint haze,	0·5	⁞⁞	12·020			57 210		18
	Very fine line,	0·5	·	12·147			57 236		26
	Fine line,	0·8	·	12·186			57 245		9
	Do.	1·	|	12·207			57 249		4
	Clear line,	1·5	|	12·238		Manganese.	57 256		7
	Strong line,	2·	┃	12·258		Manganese.	57 260		4
INDIGO.	Stronger line,	2·5	┃	12·286		Manganese.	57 266		6
	Do.	3	┃	12·300			56 269		3
	Strongest and darkest of all.	**5**	┃	**12·332**	**57 274**	Calcium.	**57 275**		6
	Double line : 1st component,	2	|	12·405			57 291		16
	2nd do.	2	|	12·435			57 298	7	
	Fine line,	1	|	12·528			57 318		20
	Faint flat band : 1st side,	2	⁞	12·588		Iron.	57 330		12
	2nd do.	2	⁞	12·635			57 340	10	
	Fine line,	1·5	|	12·718			57 358		18
	Strong double line : 1st component,	3	┃	12·804		Titanium.	57 378		20
	2nd do.	3	┃	12·905		Calcium.	57 398	20	
	Fine line,	1	|	12·986			57 414		16
	Haze band : begins sharp,	1	⁞	13·045			57 429		15
	ends weak,	0·3	⁞	13·128			57 446	17	
	Fine line,	1	|	13·340			57 492		46
	Do.	1	|	13·385		Titanium.	57 501		9
	Do.	1	|	13·433			57 512		11
	Very strong, black and hazy: 1st side,	**6**	⁞┃⁞	**13·515**	**57 530**	Iron and Manganese.	**57 529**		17
	2nd do.			**13·543**			**57 532**	3	

1h. 10m. P.M.

The field is now rather too dark, and is violet-coloured, approaching to lilac. On trying in place of present prisms 8 and 6, Disp. =21°, the whiter pair 8 and 4, Disp. =14°, the field is instantly lighter and *bluer.*

And on trying the still more transparent pair 8 and 3, Disp. =10°, the field is still lighter, and a lighter and more cobalt blue, or verging back even to glaucous blue ; the actual spectrum-place, nevertheless, as tested by the last line, being absolutely the same all through.

Similar, but *mutatis mutandis,* features having been noticed at the red end of the spectrum, it is plain that the colour has certain limits of change of place in the spectrum, according to illumination ; though spectral lines have not. The limits, however, being very small, and not sensibly marring the general law for beginners with small dispersive powers, that colour and refrangibility march together.

Saturday, June 29, 9h. 30m. A.M.

	Centre of thick hazy line,	**6**	⁞┃⁞	**6·955**	**57 530**	Iron and Manganese.	**57 530**		12

All the lines hereabouts are hazy, more or less.

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	Very fine line, } All these 6 lines wanting in Angstrom.	0·7	·	6·985			57 542		
	Fine line, .	1·3	|	7·005			57 550		8
	Do. .	1·4	·	7·054			57 568		18
	Do. .	1·3	|	7·092			57 584		16
	Clear line,	2	▮	7·114			57 593		9
	Do. .	2	▮	7·160			57 611		18
	Strong unequal double—								
	1st component, .	**4**	▮	**7·183**		Calcium and Iron.	**57 620**	11	9
	2nd component, . .	2	|	7·214			57 631		
	Strong line, ...	2	▮	7·250		Calcium.	57 646		15
	Very strong line, "little e," hazy—								
	1st side, . .	**7**	▒	**7·300**		Iron.	**57 666**	10	20
	2nd side, . .	**7**		**7·324**			**57 676**		
	Fine line, ...	2	|	7·372		Nickel ?	57 694		18
	Unequal triple group—								
	1st component, .	**4**	▮	**7·426**		Nickel.	**57 715**	13	21
	2nd component, . .	1	|	7·455			57 728	10	
	3rd component, . .	3	▮	7·482		?	57 738		
	Close double line : 1st component, .	2	|	7·527			57 755	4	17
	2nd do. .	2	|	7·538			57 759		
	Fine line, ...	1	|	7·580			57 778		19
	Do.	1	|	7·610			57 789		11
	Do.	1	|	7·628			57 795		6
	Very strong line, . . .	**4**	▮	**7·655**		Titanium.	**57 806**		11
INDIGO.	Fine double line : 1st component, .	1	|	7·685			57 818	8	12
	2nd do. .	1	|	7·704			57 826		
	Very strong line, ...	3	▮	7·764		Iron.	57 849		23
	Strong line, ...	2	▮	7·793			57 860		11
	Fine line, ...	1·5	|	7·804			57 865		5
	Strong line, ...	2	▮	7·833		Calcium.	57 875		10
	Fine line, ...	1	|	7·840			57 878		3
	Group of lines : 1st component, .	1	|	7·874			57 890		12
	2nd do. .	1·3	|	7·885			57 895	5	
	3rd do. .	1·3	|	7·896			57 898	3	
	4th do. .	1·3	|	7·910			57 906	8	
	5th and chief, .	2	▮	7·924			57 911	5	
	Strong haze band : 1st side, . .	3	▒	7·986		Calcium.	57 933	6	22
	2nd side, . .	3		7·998			57 939		
	Flat or fainter haze band : 1st side, .	2	▒	7·998			57 939	13	0
	2nd side, .	2		8·030			57 952		
	Very strong line, "little f," hazy—								
	1st side, . .	**9**	▒	**8·030**	**57 954**	Iron.	**57 952**	8	0
	2nd side, . .			**8·048**			**57 960**		
	Haze continues up to this line, . .	2	▒	8·063		Chromium.	57 965		5
	Re-focussed telescope.								
	Last line repeated, ...	2	▮	8·078		Chromium.	57 965		
	An alternating series—								
	1st component, .	2	▮	8·150			57 990		25
	2nd do. .	1	|	8·175			58 000	10	
	3rd do. .	2	▮	8·213		Calcium ?	58 013	13	
	4th do. .	1	|	8·240			58 022	9	
	5th do. .	2	▮	8·295			58 042	20	
	6th do. .	1	|	8·303			58 046	4	
	INDIGO colour ends here ; VIOLET begins.								10

olour of the Continuous pectrum at the Place.	Object Observed, generally a black, fixed Frauenhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data, from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Strong line, ...	3		8·333		Iron.	58 056		
	Very fine line, ...	0·8		8·347			58 061		5
	Fine line, ...	1·3		8·360			58 065		4
	Very fine line, ...	0·8		8·371			58 069		4
	Strong line, ...	2		8·390			58 076		7
	Fine line, ...	1		8·412			58 083		7
	Strong line, ...	2		8·438			58 094		11
	Fine line, ...	1		8·452			58 100		6
	Very powerful triple—								
	1st component, .	**4**		**8·505**		?	**58 119**		19
	2nd do. .	**4**		**8·562**		Iron.	**58 139**	20	
	3rd do. .	**5**		**8·633**		Iron.	**58 163**	24	
	Strong line, ...	2		8·670			58 177		14
	Very fine line, ...	1		8·688			58 183		6
	A notable group—								
	1st component, . .	1		8·760			58 209		26
	2nd and chief do. .	3		8·792			58 221	12	
	3rd do. .	2·5		8·806			58 226	5	
	4th do. .	2·		8·815			58 229	3	
	5th do. .	1		8·825			58 232	3	
	A triple group—								
	1st and smallest component, .	1		8·888			58 254		22
IOLET.	**2nd and large do.** .	**4**		**8·920**		Chromium.	**58 266**	12	
	3rd and large do. .	**4**		**8·955**		Iron.	**58 278**	12	
	A band of small lines: 1st component,	1		9·034			58 305		27
	2nd do. .	1		9·050			58 311	6	
	3rd do. .	2		9·073			58 319	8	
	4th do. .	2		9·095			58 328	9	
	Quadruple group—								
	1st component, . .	2		9·164			58 352		24
	2nd and chief do.	**5**		**9·195**	**58 360**	Chromium and Iron.	**58 362**	10	
	3rd, a thin line, . .	1		9·232			58 377	15	
	4th, do. . .	1		9·240			58 380	3	
	Strong line (barely seen in Angstrom),	3		9·344			58 416		36
	Strong line, ...	2		9·405			58 440		24
	Unequal triple group—								
	1st component, .	2		9·477		Chromium.	58 468		28
	2nd do. .	1		9·495			58 474	6	
	3rd and chief do. .	3		9·527		Iron.	58 485	11	
	Violet Hydrogen, sometimes called, "near G"—								
	Haze begins, . .	0·5		9·604			58 512		27
	1st side of lines, .	10		**9·618**	**58 524**	Hydrogen.	**58 519**		7
	2nd do. .			**9·645**			**58 530**	11	
	Following line,	**4**		**9·665**		Chromium and Titanium.	**58 538**	8	
	Fine line, ...	1		9·720			58 561		23
	Do.	1		9·730			58 565		4
	Stronger line, ...	2		9·745			58 571		6
	Very strong line, . . .	**4**		**9·760**			**58 578**		7
	Fine line, ...	1		9·821			58 601		23
	Stronger line, ...	2		9·867			58 619		18
	Fine line, ...	1		9·914			58 638		19
	Do.	1		9·950			58 652		14
	Strong line, ...	2		9·972			58 660		8
		1·5		10·062			58 698		38
									15

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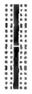
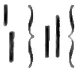
								Breadths & Doubles.	Distances.
		2		10·103			58 713		
	Grand line, followed by lines in haze—								
	1st grand line, . . . haze intervenes.	**8**		**10·135**	**58 727**	Iron.	**58 726**		13
	2nd next grand line, . haze intervenes.	**4**		**10·170**			**58 738**	12	
	3rd line, ... haze intervenes.	1		10·210			58 752	14	
	4th line, ... haze intervenes.	2		10·223			58 757	5	
	5th line, ...	3		10·244		Titanium.	58 765	8	
	Fine line, ...	1		10·304			58 786		21
	Strong line, ...	3		10·337		Titanium.	58 796		10
	Less strong line, ...	2		10·424		Calcium.	58 827		31
	Fine line, ...	1		10·495			58 851		24
	Sharp double line: 1st component, .	2		10·568		Iron and	58 877		26
	2nd do. .	2		10·602		Titanium.	58 888	11	
	Fine double line: 1st component, .	1		10·648		Titanium.	58 902		14
	2nd do. .	1		10·665			58 909	7	
	Fine double line: 1st component, .	1		10·700			58 922		13
	2nd do. .	1		10·715			58 926	4	
	Fine line, ...	1·5		10·735			58 933		7
	Do.	1·5		10·745			58 938		5
	Do.	1·5		10·755			58 941		3
	Do.	1·5		10·767			58 944		3
VIOLET.	Strong line, ...	3		10·780			58 949		5
	Less strong line, ...	2		10·790			58 952		3
	Fine line, ...	1		10·808			58 959		7
	The Great G line—								
	1st side, .			**10·823**			**58 964**		5
	middle, .	**10**		**10·838**	**58 967**	Iron.	**58 968**	4	
	last side, .			**10·850**			**58 973**	5	
	Sharp line, ...	3		10·877		Calcium.	58 982		9
	Triple group: 1st component, . .	2		10·907			58 993		11
	2nd do. . .	1·5		10·915		Titanium.	58 997	4	
	3rd do. . .	2		10·926			59 000	3	
	Strong line, ...	3		10·954			59 009		9
	Do.	2		10·995			59 023		14
	Hazy quadruple group—								
	1st component, . .	1		11·024			59 032		9
	2nd do. . .	3		11·038			59 038	6	
	3rd do. . .	1		11·043			59 040	2	
	4th do. . .	3		11·054		Calcium.	59 043	3	
	A group of lines and haze bands, terminated by a very strong line,	2		11·087		Calcium.	59 055		12
		1		11·108			59 062		7
		2		11·132			59 070		8
		1		11·150		Titanium.	59 077		7
		5		**11·173**		Calcium and Iron.	**59 085**		8
	Strong line, ...	2		11·216			59 100		15
	Strong double line: 1st component, .	3		11·245		Iron.	59 110		10
	2nd do. .	3		11·265			59 118	8	
	Unequal double line: 1st component,	3		11·335		Titanium.	59 141		23
	2nd do. .	**5**		**11·385**		Iron.	**59 159**	18	11

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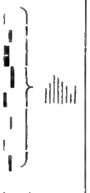
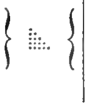
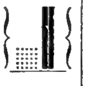
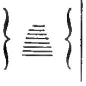
	Fine line and sharp,	1		11·415			59 170		14
	Strong line and sharp,	3		11·456			59 184		16
	Very strong and sharp line,	**4**		**11·503**		Titanium.	**59 200**		12
	Group of lines: 1st component,	1		11·536		Chromium and Calcium.	59 212	7	
	2nd and chief,	3		11·553			59 219	3	
	3rd component,	1		11·564			59 222	4	
	4th do.	1		11·577			59 226	4	
	5th do.	0·5		11·583			59 230		12
	Single, strong, and sharp line,	3		11·620		Titanium.	59 242		12
	Group of 8 lines: 1st component,	1		11·655		Titanium, Iron, and Calcium.	59 254	6	
	2nd do.	2		11·673			59 260	8	
	3rd and chief,	**4**		**11·695**			**59 268**	6	
	4th component,	3		11·713			59 274	3	
	5th do.	2		11·722			59 277	3	
	6th do.	1		11·732			59 280	7	
	7th do.	0·5		11·754			59 287	7	
	8th do.	2		11·775			59 294		15
	Triple group: 1st component,	1		11·818		Iron.	59 309	6	
	2nd do.	2·5		11·835			59 315	5	
	3rd do.	1		11·850			59 320		14
	Strong lines in haze band—								
	1st	2		11·890		Manganese.	59 334	10	
	2nd	3		11·920			59 344	8	
	3rd and chief,	**4**		**11·945**			**59 352**		10
	Fine line,	1		11·972			59 362		8
	Do.	1		11·994			59 370		
	Decreasing haze band—								12
VIOLET.	begins sharp,	2		12·025		Copper.	59 382		8
	middle,	1·5		12·046			59 390		3
	vanishes,	0·1		12·060			59 393		
	Very powerful line, and other lines in a haze band—								17
	1st line,	3		12·107		Chromium and Calcium.	59 410	10	
	2nd and chief,	**6**		**12·138**			**59 420**	11	
	3rd line,	2		12·170			59 431	7	
	4th do.	3		12·188			59 438		
	11h. A.M.								25
	Very powerful double—								
	1st component,	**6**		**12·260**	**59 467**	Iron.	**59 463**	7	
	2nd do.	**6**		**12·278**			**59 470**		23
	Powerful line,	**4**		**12·345**			**59 493**		13
	Fine line,	1		12·384			59 506		12
	Triple group: 1st component,	3		12·424		Iron.	59 518	9	
	2nd do.	1		12·445			59 527	6	
	3rd do.	3		12·463			59 533		15
	Very fine line,	0·5		12·505			59 548		7
	Fine line,	1		12·524			59 555		8
	Strong line,	2·5		12·550		Iron.	59 563		7
	Do.	2		12·570		Iron.	59 570		16
	Fine line,	1		12·613			59 586		17
	Fine line, followed by haze,	2		12·668			59 603		
	Very powerful line, reached by said haze—								17
	1st side, **2nd do.**	**10**		**12·715** **12·745**	**59 623**	Iron.	**59 620** **59 630**	10	12
	Hazy band—begins,	0·5		12·780		Manganese.	59 642		10
	maximum,	2		12·810			59 652		5
	ends,	0·5		12·824			59 657		23

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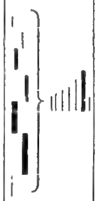
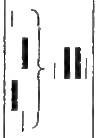
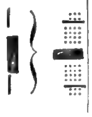
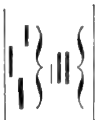
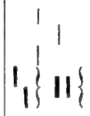
	System of lines, very sharp—								
	1st component,	1		12·890		Chromium, Calcium, and Iron.	59 680		
	2nd do.	2		12·905			59 686	6	
	3rd do.	3		12·914			59 689	3	
	4th do.	**4**		**12·924**			**59 693**	4	
	5th do.	**5**		**12·941**			**59 698**	5	
	6th and chief,	**7**		**12·968**			**59 707**	9	
	7th component,	2		12·987			59 714	7	
	Group of lines—								
	1st and small component,	1		13·040			59 733		19
	2nd and powerful,	**6**		**13·110**	**59 758**	Iron.	**59 758**	25	
	3rd do. do.	**6**		**13·134**	**59 765**	Iron.	**59 765**	7	
	4th component, small,	2		13·154			59 771	6	
	Fine unequal double line—								
	1st component,	0·5		13·198		Iron.	59 786		15
	2nd do.	2·		13·216			59 793	7	
VIOLET.	**Grand double line—**								
	1st component,	**4**		**13·252**			**59 805**		12
	2nd do.	**4**		**13·282**			**59 814**	9	
	Fine line,	1		13·309			59 821		7
	Strong line,	2		13·348		Iron.	59 837		16
	Strong group of lines: 1st component,	3		13·430			59 863		26
	2nd do.	3		13·465			59 875	12	
	3rd do.	3		13·473			59 878	3	
	Group of alternating lines,	1		13·558		Iron.	59 905		27
		3		13·585			59 918		13
		1		13·602			59 921		3
		3		13·623			59 928		7
		1		13·638			59 932		4
		3		13·656		Iron.	59 940		8
	A grand triple group, where place appears to be faulty in Angstrom's Map—								
	1st line,	3		13·695		Titanium.	59 952		12
	2nd and chief line,	**8**		**13·736**	**59 959?**	Iron.	**59 965**	13	
	3rd and last line, haze includes all three.	3		13·768			59 975	10	
	VIOLET colour ends here; LAVENDER begins.								29
	Triple group (single in Angstrom)—								
	1st line,	3		13·845		Iron.	60 004		
	2nd do.	**4**		**13·854**		Iron.	**60 007**	3	
	3rd do.	**4**		**13·866**		?	**60 012**	5	
	Fine line,	1		13·912			60 029		17
	Strong line,	2		13·945			60 041		12
	Do.	2		13·965			60 047		6
Lavender.	Strong double line: 1st component,	3		13·988		Iron.	60 054		7
	(Single in Angstr.), 2nd do.	3		14·000			60 060	6	
	"Little g," a very powerful and hazy line: haze begins,	0·5		14·080		Manganese.	60 089		29
	1st side of g,	**10·**		**14·107**	60 100	Calcium.	**60 100**		11
	2nd side of g,	**10·**		**14·128**			**60 103**	3	
	Terminal line to the haze,	**4·**		14·162		Calcium.	**60 114**	11	14

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	Fine line, ...	1		14·208			60 128		5
	Do.	1		14·225			60 133		9
	Very fine line, ...	0·5		14·252			60 142		3
	Do. do.	0·5		14·262			60 145		16
	Powerful line and sharp, .	**4**		**14·313**		Iron.	**60 161**		8
	Fine line (not in Angstrom), . .	2		14·340			60 169		17
	Fine line, ...	2		14·398			60 186		13
	Strong and sharp line (not in Angstrom), ...	**4**		**14·440**			**60 199**		10
	Fine line, ...	1		14·471			60 209		16
	Double line: 1st component, . .	1		14·525		Iron.	60 225	3	
	2nd do. . .	2		14·534			60 228		14
	A grand triplet—								
	1st line, ...	**4**		**14·583**			**60 242**	9	
	2nd and chief, .	**8**		**14·610**	**60 251**	Calcium and Iron.	**60 251**	5	
	3rd and last line, . .	3		14·621			60 256		22
	Fine line (stronger in Angstrom), .	1		14·683		Iron.	60 278		14
	Do.	1		14·724			60 292		11
	Do.	1		14·760			60 303		14
	Stronger line, ...	2		14·793			60 317		3
	Fine line, ...	1		14·809			60 320		10
	Very strong line and sharp,	**5**		**14·835**		Iron.	**60 330**		6
	Strong line, ...	2		14·852		Iron.	60 336		14
	Do.	2		14·898		Iron.	60 350		23
	Fine line, ...	1		14·960			60 373		8
	Strong line and sharp, . . .	3		14·985		Iron.	60 381		19
avender.	Fine line, ...	1		15·038			60 400		7
	Do. (strong line in Angstrom),	1		15·056		Iron.	60 407		13
	Do.	1		15·098			60 420		3
	Do.	1		15·107			60 423		25
	Very powerful line—								
	1st side,	**10**		**15·174**	**60 452**	Iron.	**60 448**	6	
	2nd do.			**15·197**			**60 454**		15
	Fine line, ...	1		15·240			60 469		11
	Do.	1		15·275		Iron.	60 480		11
	Strong line, ...	3		15·316		?	60 491		5
	Clear line, ...	2		15·332			60 496		6
	Very powerful line (double in Angstrom)—								
	1st side, .	**10**		**15·348**	**60 502**	Iron.	**60 502**	5	
	2nd do. .			**15·363**			**60 507**		24
	Very faint double line—								
	1st component, .	1		15·435		Iron.	60 531	2	
	2nd do. .	1		15·443			60 533		11
	Strong double line: 1st component, .	3		15·475			60 544	11	
	2nd do. .	1		15·505			60 555		18
	Strong line, ...	2		15·562		Calcium.	60 573		17
	Fine line, ...	1		15·614			60 590		12
	Very powerful line and hazy, ...	**8**		**15·655**	**60 602**	Iron.	**60 602**		10
	Fine line, ...	2		15·680			60 612		34
	11h. 35m. A M.								
	Strong line, ...	3		15·773		Calcium.	60 646		16

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Very strong line and sharp,	5		15·820	60669	Iron.	60 662		
	Very strong line and sharp, but with haze behind, .	5		15·844			60 672	10	
	Said haze ends, ...	0·5		15·863			60 680		8
	Very strong line, . . .	4		15·866		Titanium.	60 681		1
	Strong line, ...	2		15·955			60 709		28
	Very strong line, . . .	4		15·990		Iron.	60 720		11
	Fine line, ...	1		16·010			60 727		7
	Do.	1		16·025			60 732		5
	Strong line, ...	2		16·036			60 736		4
	Fine line, ...	1		16·053			60 742		6
	Do.	1		16·072			60 747		5
	Very powerful line, . .	6		16·095		Iron.	60 755		8
	Fine line, ...	1		16·136			60 769		14
	Strong and sharp line, . . .	3		16·202			60 789		20
	Fine line, ...	1		16·216			60 793		4
	Do.	1		16·267			60 810		17
	Very strong line, . . .	4		16·280		Iron.	60 813		3
	Strong line and sharp, . . .	3		16·330		Iron.	60 830		17
	Strong line, ...	2		16·378		Iron.	60 846		16
	Do.	2		16·412		Iron.	60 857		11
	Band of sharp lines, but with haze behind—								
	1st component, . .	2		16·458		Iron and Titanium.	60 871		14
	2nd and chief do. .	4		16·486			60 880	9	
	3rd component, . .	3		16·514			60 889	9	
	4th and last do. . .	2		16·554			60 902	3	
Lavender.	Strong line, ...	2		16·592			60 913		11
	Fine line, ...	1		16·643			60 930		17
	Do.	1		16·695			60 948		18
	Triplet: 1st component, . . .	2		16·738		Iron.	60 961		13
	2nd and chief do. .	6		16·762			60 970	9	
	3rd and faintest line, . .	1		16·774			60 973	3	
	Strong line, ...	3		16·845		?	60 998		25
	Fine line, ...	1		16·880			61 008		10
	Strong line, ...	3		16·925		Titanium.	61 022		14
	Very faint double line—								
	1st component, . .	1		17·020			61 053		31
	2nd do. . .	1		17·030			61 056	3	
	Very fine line, ...	0·5		17·063			61 068		12
	Double line: 1st component, . .	1		17·120		Iron.	61 083		15
	2nd do. . .	1		17·135		Iron.	61 090	7	
	Fine line, ...	1		17·180			61 103		13
	Strong close double—								
	1st component, .	4		17·237	61 124	Iron.	61 121		18
	2nd do. .	4		17·255			61 126	5	
	Wider strong double—								
	1st component, .	4		17·323	61 147	Iron.	61 144		18
	2nd do. .	4		17·363			61 155	11	
	Very strong line, . . .	5		17·454		Iron.	61 183		28
	Strong line, ...	3		17·538		Iron.	61 209		26
	Do.	2		17·555			61 215		6
	Fine line, ...	1		17·560			61 217		2
	Powerful line, ...	5		17·582		Iron.	61 223		6
	Strong line, ...	2		17·664		Iron.	61 249		26
									22

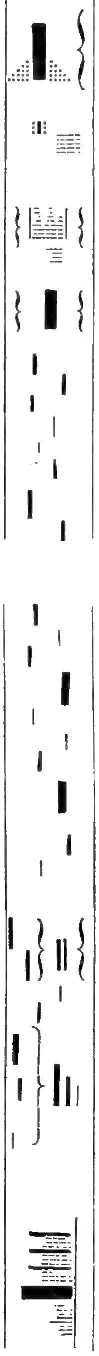
olour of the Continuous pectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
	Fine line, ...	1	|	17·735			61 271		
	Very powerful and close double—								
	1st line, .	**6**	‖	**17·834**	**61 305**	Iron.	**61 302**	6	31
	2nd do. .	**6**	‖	**17·851**			**61 308**		
	Strong line (not in Angstrom), . .	3	▌	17·898			61 322		14
	Fine line, ...	1	|	17·914			61 328		6
	Do.	1	|	18·004			61 358		30
	Very fine line, ...	0·8	|	18·016			61 362		4
	Triplet: 1st line, ...	1	|	18·120		?	61 394		32
	2nd, and chief line, . .	3	|	18·145			61 402	8	
	3rd, and last line, . .	1	|	18·163			61 408	6	
	Very powerful line, and thick, ...	**7**	▌	**18·274**	**61 440**	Iron.	**61 442**		34
	Strong line, ...	3	▌	18·297			61 450		8
	Do.	3	▌	18·354		Iron.	61 470		20
	Very powerful and thick line, ...	**6**	▌	**18·393**	**61 478**	Iron.	**61 480**		10
	Fine line (not in Angstrom), . .	2	|	18·485			61 509		29
	Do. do. . .	2	|	18·520			61 520		11
	Double line: 1st component, . .	2	|	18·586		Iron.	61 538		18
	2nd do. . .	2	|	18·594			61 542	4	
		2	|	18·662			61 563		21
		2	|	18·695			61 575		12
vender.	Double line: 1st component, . .	2	|	18·790			61 602		27
	2nd do. . .	2	|	18·800			61 606	4	
	Very strong line, ...	**4**	▌	**18·843**		Iron.	**61 620**		14
	Strong line, ...	3	▌	18·865		Iron.	61 626		6
	Fine line, ...	1	|	18·910			61 639		13
	Do.	1	|	18·953			61 653		14
	Do.	1	|	18·975			61 659		6
	Very powerful and thick line, ...	**8**	▌	**19·001**	**61 667**	Iron.	**61 667**		8
	Strong line, ...	3	▌	19·054			61 682		15
	Do.	2	▌	19·135			61 708		26
	Fine line, ...	1	|	19·145			61 712		4
	Strong line, ...	2	▌	19·195			61 727		15
	Fine line, ...	1	|	19·232			61 738		11
	Very strong line, ...	**4**	▌	**19·297**			**61 757**		19
	Fine line, ...	1	|	19·330			61 768		11
	Strong line, ...	3	▌	19·361			61 779		11
	Fine line, ...	1	|	19·390			61 787		8
	Powerful line, ...	**5**	▌	**19·415**			**61 795**		8
	(From 61 667 to 61 880 entirely blank in Angstrom).								13
	Powerful line, ...	**4**	▌	**19·455**			**61 808**		
	Very strong line, ...	3	▌	19·465			61 811		3
	Strong line, ...	2	▌	19·485			61 818		7
	Fine line, ...	1	|	19·505			61 823		5
	Very fine line, ...	0·5	|	19·535			61 833		10
	Powerful line, .	**4**	▌	**19·576**			**61 844**		11
	Strong line, ...	2	▌	19·634			61 863		19
									17

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
Lavender.	**Notable haze-enveloped group, containing the important and thick line representing Lavender-Hydrogen—**								
	1st component,	4	❙	19·690			61 880		
	2nd, with haze,	4	❙	19·730			61 892		12
	3rd, with haze,	4	❙	19·790			61 911		19
	4th, being the first side of grand line,	10	▮	19·835			61 925		14
	5th, being the second side of the grand line,	10	▮	19·873		Hydrogen.	61 938	13	
	6th, being end of the haze,	1	⁝	19·975			61 969		31

Monday, July 1, 1878. Prisms 8 and 4. Dispersion = 14°.

At 0h. 50m. came a sudden clearing of sky after a cloudy morning. Began immediately to work the apparatus, but the day's measures, from 61 923 to 62 822, are most unfortunately not of the standard degree of definition.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences. Breadths & Doubles.	Differences. Distances.
Lavender.	**Lavender-Hydrogen repeated for place only—**								
	1st side,	10	▮	9·340	61 931	Hydrogen.	61 923	12	
	2nd do.	10	▮	9·368			61 935		
	Haze, attending it, ends,	0·5	⁝	9·440			61 958		23
	Strong hazy band: 1st side,	2	⁝	9·505		Calcium.	61 976	10	18
	2nd do.	2	⁝	9·534			61 986		
	Weak hazy band,	1	⁝	9·583		Calcium.	62 002		16
	Hazy band or line,	2	⁝	9·630			62 017		15
	Broad hazy band: 1st and sharp side,	3	⁝	9·674			62 030	10	13
	2nd and weak do.	1		9·705			62 040		
	Hazy band or line: 1st side,	3	⁝	9·786	62 061	Calcium.	62 065	5	25
	2nd do.	3		9·803			62 070		
	Strong line,	3	❙	9·842			62 083		13
	Graduated haze band—								
	1st and faint side,	1	⁝	9·870			62 093	13	10
	2nd and strong side,	4		9·910			62 106		
	Hazy line,	3	⁝	9·955			62 119		13
	Do.	3	⁝	9·972			62 126		7
	Hazy band,	3	⁝	10·045			62 149		23
	Hazy band line,	4	⁝	10·083			62 162		13
	Stronger hazy band line,	5	⁝	10·140		Iron.	62 180		18
	Hazy band line,	3	⁝	10·173			62 191		11
	Broad hazy group—								
	1st and stronger part,	6	⁝	10·213		Manganese.	62 204	23	13
	2nd and weaker part,	3		10·285			62 227		
	Faint haze band,	1	⁝	10·344			62 246		19
	Stronger haze band,	2	⁝	10·395			62 262		16
	Still stronger haze band, sharpest on 2nd side,	4	⁝	10·435			62 276		14
	Faint haze band,	2	⁝	10·490			62 294		18
	Very strong haze band line,	5	⁝	10·515	62 305	Calcium.	62 302		8
	Powerful hazy group—								
	1st and stronger part,	6	⁝	10·556			62 315	15	13
	2nd and weaker part,	3		10·604			62 330		
	Hazy band line,	2	⁝	10·662			62 349		19
	Do. do.	2	⁝	10·715			62 366		17
									14



olour of the Continuous pectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Grand line with haze—								
	Haze begins,	0·5		10·760			62 380		
	1st side of line,	**10**		**10·800**	62 390	Iron.	**62 392**	12	
	2nd do.	**10**		**10·819**			**62 396**	4	
	Haze ends,	0·5		10·855			62 408	12	
	Hazy line,	2		10·928			62 430		22
	Stronger hazy line band,	**4**		**10·985**			**62 449**		19
	Broad haze band, almost resolved into lines—								10
	1st side,	**4**		**11·017**			**62 459**		
	2nd do.	**4**		**11·072**			**62 476**	17	
	Hazy band line,	2		11·113			62 488		12
	Very powerful line: 1st side,	**8**		**11·185**	62 516	Iron.	**62 510**		22
	2nd do.	**8**		**11·220**			**62 521**	11	
	Strong line,	3		11·247			62 529		8
	Do.	3		11·250			62 530		11
	Decided line,	2		11·286			62 541		11
	Do.	2		11·307			62 548		7
	Fine line,	1		11·395			62 573		25
	Strong line,	2		11·423			62 582		9
	Powerful line,	**4**		**11·450**			**62 590**		8
	Strong line,	2		11·470			62 596		6
	(All this part very imperfect in Angstrom.)								4
	Strong line,	2		11·483			62 600		
	Fine line,	1		11·500			62 605		5
	Strong line,	2		11·506			62 607		2
	Powerful and thick line,	**5**		**11·527**			**62 613**		6
vender.	Fine line,	1		11·580			62 628		15
	Strong line,	2		11·610			62 638		10
	Stronger line,	3		11·626		Manganese.	62 643		5
	Powerful and thick line,	**5**		**11·650**		Manganese.	**62 650**		7
	Strong line,	2		11·690			62 662		12
	Do.	2		11·712			62 669		7
	Fine line,	1		11·730			62 674		5
	Strong double line—								14
	1st component,	**4**		**11·774**		Iron.	**62 698**		
	2nd do.	**4**		**11·787**			**62 690**	2	
	Fine line,	1		11·835			62 705		15
	Strong line,	2		11·863			62 715		10
	Triplet of lines—								13
	1st and strongest,	**4**		**11·904**		Manganese.	**62 728**		
	2nd and intermediate,	3		11·932			62 735	7	
	3rd and weakest,	2		11·960			62 743	8	
	A grandly powerful line set in haze, and other fine lines—								21
	Haze begins,	0·3		12·030			62 764		
	Fine line in haze,	1		12·075			62 778	14	
	1st side of grand line,	**10·**		**12·100**	62 790	Iron.	**62 786**	8	
	2nd do. do.	**10·**		**12·145**			**62 799**	13	
	Strong line in haze,	**4**		**12·165**			**62 804**	5	
	Do. do.	**4**		**12·195**			**62 813**	9	
	Do. do.	**4**		**12·225**			**62 822**	9	
									43

1h. 15m. P.M. Only one more very powerful line before H^1.—The lines this morning are very hazy and "worstedy," perhaps from deficient illumination.

Tuesday July 2nd, 1878. Prisms altered; being now Prisms 8 and 3, Dispersion = 10. The illumination is therefore brighter, and the definition improved, but the Dispersion is now too small for much accuracy.

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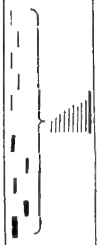
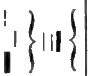
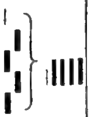
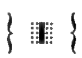
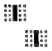
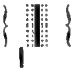
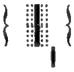
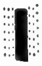
								Breadths & Doubles.	Distances.
Lavender.	**The last grand line alone, repeated for place—**								
	1st side, .	**10**		**8·124**	**62 790**	Iron.	**62 783**	13	
	2nd do. .	**10**		**8·153**			**62 796**		
	Triplet of sharp lines—								
	1st, and strongest, .	**5**		**8·302**		Iron.	**62 865**		
	2nd, and moderate, .	3		8·320			62 870	5	
	3rd, do. .	3		8·348			62 884	14	
	Hazy double line: 1st component, .	2		8·388			62 900	16	
	2nd do. .	2		8·395			62 906	6	
	Faint band, ...	1		8·455			62 933		27
	Powerful double—								45
	1st component, .	**4**		**8·560**	**62 984**	Manganese.	**62 978**		
	2nd do. .	**4**		**8·585**			**62 989**	11	
	Strong double line: 1st component, .	3		8·604			62 999		10
	2nd do. .	3		8·620			63 005	6	
	Strong line, ...	2		8·654			63 019		14
	Very powerful line—								13
	1st side, .	**6**		**8·683**	**63 035**	Manganese.	**63 032**		
	2nd .	**6**		**8·704**			**63 040**	8	
	Strong line, ...	2		8·729			63 050		10
	A long hazy band of fine lines, terminated by a powerful line—								16
	1st component, . .	1		8·765			63 066		
	2nd do. . .	1		8·783			63 073		7
	3rd do. . .	1		8·797			63 079		6
	4th do. . .	1		8·813			63 086		7
	5th do. . .	1·5		8·825			63 090		4
	6th do. . .	2		8·844			63 098		8
	7th do. . .	2		8·857			63 103		5
	8th do. . .	2		8·870			63 109		6
	9th do. . .	3		8·888			63 117		8
	10th, and chief, .	**5**		**8·910**		Iron.	**63 127**		10
	Band ended by a strong line—								8
	1st component, . . .	2		8·932			63 135		
	2nd do. . . .	2		8.945			63 141		6
	3rd do. . . .	2		8·980			63 156		15
	4th, and chief line, .	**4**		**9·008**			**63 168**		12
	Strong line, ...	3		9·034			63 180		12
	Powerful line, ...	**5**		**9·060**			**63 190**		10
	Strong line, ...	2		9·104			63 208		18
	Strong triplet of lines—								16
	1st component, .	**4**		**9·142**	**63 231**	Iron.	**63 224**		
	2nd do. .	3		9·162			63 231	7	
	3rd do. .	3		9·170			63 236	5	
	Very fine line, ...	1		9·202			63 252	16	
	Fine line, ...	1		9·223			63 262		10
	Strong double line: 1st component, .	3		9·278			63 286		24
	2nd do. .	3		9·295			63 290	4	
	Band of 6 lines: 1st component, .	3		9·356			63 316		26
	2nd do. .	2		9·377			63 324	8	
	3rd do. .	2		9·398			63 332	8	
	4th do. .	3		9·420			63 340	8	
	5th do. .	3		9·455			63 353	13	
	6th do. .	3		9·483			63 364	11 21	

From 63 230 to 63 400 empty in Angstrom; but apparently from instrumental insufficiency only.

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
	Solitary line,	2		9·528			63 385		
	Band of small lines: 1st line,	2		9·552			63 396		11
	2nd do.	3		9·566			63 400	4	
	3rd do.	3		9·586			63 409	9	
	4th do.	1		9·594			63 412	3	
	Very powerful and black line—								8
	1st side,	**9**		**9·622**	**63 419**	Iron.	**63 420**		
	2nd do.	**9**		**9·640**			**63 426**	6	
	Fine line,	2		9·670			63 442		16
	Do.	2		9·709			63 460		18
	Very fine line,	1		9·727			63 468		8
	Do. do.	1		9·736			63 470		2
	Triplet of strong lines—								7
	1st component,	2		9·753			63 477		
	2nd do.	2		9·777			63 486	9	
	3rd and chief,	**4**		**9·804**			**63 500**	14	
	A group of one moderate and four very strong lines,	2		9·845	**63532**	Iron.	63 517		17
		4		**9·858**			**63 524**	7	
		4		**9·881**			**63 534**	10	
		4		**9·904**			**63 542**	8	
		4		**9·920**			**63 548**	6	
	Quadruple group of lines—								13
	1st component,	2		9·953			63 561		
	2nd do.	3		9·970			63 570	9	
	3rd do.	**4**		**9·997**			**63 579**	9	
	4th do.	3		10·030			63 598	19	
Lavender.	Fine line,	2		10·060			63 612		14
	Do.	2		10·095			63 630		18
	Do.	2		10·130			63 640		10
	Unequal double line—								18
	1st and stronger,	**4**		**10·168**			**63 658**		
	2nd and weaker,	2		10·210			63 680	22	
	Haze band,	2		10·225	63 686	Manganese.	63 686		6
	Hazy line: 1st side,	**4**		**10·285**			**63 710**		24
	2nd do.			**10·312**			**63 722**	12	
	All these lines are more or less thick and hazy, and in an atmosphere (solar and spectral) of haze,	2		10·358			63 743		21
		4		**10·414**			**63 764**		21
		2		10·460			63 783		19
		3		10·493			63 798	15	
		3		10·518			63 814	16	
		2		10·590			63 836	22	
		3		10·623			63 850	14	
		3		10·645			63 860	10	
		2		10·675			63 874	14	
		4		**10·719**			**63 887**	13	
	Hazy line,	3		10·796			63 922		35
	Do.	3		10·827			63 937		15
	The grand haze of H¹ begins,	1		10·830			63 938		1
	The first side of the grandly black H¹,	**10**		**10·964**	**64 012**	Iron and Calcium.	**63 993**		55
	The second side of the grandly black H¹,	**10**		**11·065**			**64 032**	39	
	The grand haze of H¹ ends nearly,	1		11·234			64 105		73
	Prisms re-adjusted.								12
	Centre of the grand H¹ line as above, for new starting,	**10**		**11·827**	**64 012**		**64 012**		

Colour of the Continuous Spectrum at the Place.	Object Observed, generally a black, fixed Fraunhofer Line.	Intensity of black, or thickness of line.	Appearance by graphical comparative symbol.	Micrometer Reading. Rev.	PLACE-DATA, from Angstrom's Grating Normal Solar Spectrum.	Chemical-origin-data from Angstrom, Thalen, &c.	Concluded WAVE-NUMBER-PLACE, per British Inch.	Differences.	
								Breadths & Doubles.	Distances.
Lavender.	**Hazy thick line: 1st side,**	**4**		**12·074**	**64 114**	Aluminium	**64 117**	11	
	2nd do.	**4**		**12·113**			**64 128**		
	Finer line,	3		12·235			64 192		64
	Hazy thick line: 1st side,	**4**		**12·283**			**64 216**	5	24
	2nd do.	**4**		**12·300**			**64 221**		
	Finer line,	3		12·323			64 232		11
	Hazy thick line: 1st side,	**4**		**12·424**	**64 284**	Iron.	**64 280**	10	48
	2nd do.	**4**		**12·444**			**64 290**		
	Hazy unequal band: 1st side,	3		12·585			64 349	32	59
	2nd do.	3		12·668			64 381		
	Hazy strong line group—								
	1st side,	**5**		**12·753**	**64 424**	Aluminium	**64 417**	13	36
	2nd do.	**6**		**12·790**			**64 430**		
	Faint band,			12·884			64 463		33
	The grand gloomy haze of H^2 begins,			12·925			64 480		17
	The first side of the grandly black H^2 line,	**10**		**13·122**	**64 582**	Iron and Calcium.	**64 556**	51	76
	The second side of the grandly black H^2 line,	**10**		**13·275**			**64 607**		
	The grand gloomy haze of H^2 ends nearly,			13·420			64 654		47
	Hazy line darkest to right,	**6**		**13·420 ?**			**64 654**		0
	Hazy line,	3		13·610 ?			64 718		64
	Very dark hazy group,	**7**		**13·728 ?**			**64 759**		41
	Fainter haze group,	2		14·324 ?			64 960		1

All the last 20 observed subjects have been badly defined, unsatisfactory and deficient in light; while the spectrum itself and all light formed thus, it is to be remembered, through glass and noted by the eye alone, ends at the last one.

PART IV.—METEOROLOGICAL JOURNAL, CAMPOLIDE DE BAIXO, near LISBON. Kept by MRS PIAZZI SMYTH, to accompany the *first* Solar Spectrum of 1878.

Date. June 1878. Day.		Date. Hour.	Bar.	Thermometers in shade—open air. Dry Bulb.	Wet Bulb.	Last night's min.	This day's max. Hour.	This day's max.	Hygrometrical results. Temp. of Dew Point.	Elastic Force of Vapour.	Weight of Vapour in Cubic foot of Air.	Humidity Sat. =100.	Wind. Velocity	Wind. Direction.	Clouds 0 to 10.	Spectrum of Low Sky. Rain Band 0 to 10.	Low Sun Band 0 to 10.	REMARKS.
			Inches	°	°	°		°	°	in.	grs.		M.P.H.					
8th	♄	8·30 A.M.	30·20	67·3	63·5	63·0	2 P.M.	77·3	60·5	·528	5·74	79	4	S.W.	9	4	2	A little rain and fog. Earthquake at 11 P.M. on the night of the 7th.
9	☉	,,	30·10	71·0	63·0	53·5	4 ,,	78·0	56·9	·464	5·10	61	8	N.	7	3	2	
10	☾	,,	30·10	69·5	60·2	51·8	6 ,,	77·8	53·0	·403	4·41	55	3	N.E.	2	2	2	
11	♂	,,	30·05	69·2	61·9	51·7	6 ,,	72·8	56·2	·452	4·95	63	2	S.W.	6	4	2	Wind blew strong for some hours.
12	☿	,,	30·15	71·2	63·8	58·6	,,	71·5	58·2	·486	5·32	64	1	N.	5	3	2	
13	♃	,,	30·12	66·3	60·3	54·5	,,	72·3	55·5	·440	4·86	68	12	N.	5	4	3	Wind westerly, blowing almost a gale at 11 A.M. Barometer fell slowly from 1.30 P.M. until about 5 P.M.
14	♀	,,	30·03	69·0	62·1	61·8	2 ,,	75·2	56·7	·460	5·03	64	7	N.W.	8	3	2	Some rain fell last night.
15	♄	,,	30·20	67·8	60·0	55·5	,,	71·4	53·8	·415	4·54	61	8	N.	4	3	2	Strong northerly wind during the day.
16	☉	,,	30·11	68·7	60·8	57·5	,,	71·3	54·6	·428	4·67	60	6	N.E.	0	4	2	Wind blew strong all day from the N.E.
17	☾	,,	30·08	71·8	60·1	59·5	,,	76·0	51·2	·378	4·14	49	4	N.W.	9	4	2	
18	♂	,,	30·02	71·1	65·0	60·0	,,	74·7	60·3	·525	5·69	69	2	W.N.W.	10	4	1	Clouds. A heavy shower of rain fell about 9 A.M.
19	☿	,,	30·09	69·5	61·7	54·8	,,	72·3	55·6	·444	4·86	61	1	N.	0	2	2	
20	♃	,,	29·98	72·0	63·3	55·2	,,	77·0	56·7	·463	5·09	58	1	S.W.	10	4	2	South-west wind brings up black smoke from the suburbs of Lisbon.
21	♀	,,	30·07	70·6	62·0	58·5	,,	75·5	55·4	·439	4·84	59	2	N.W.	0	3	2	
22	♄	,,	30·15	72·3	64·9	60·2	,,	76·0	59·3	·508	5·51	63	1	N.W.	0	3	2	
23	☉	,,	30·06	73·5	65·0	60·5	,,	80·0	58·8	·496	5·35	60	3	N.	0	4	2	
24	☾	,,	30·08	73·7	65·5	60·0	,,	77·7	59·5	·510	5·53	62	5	N.	0	4	2	
25	♂	,,	30·05	75·2	65·5	61·8	,,	78·2	58·5	·492	5·33	56	8	N.	0	3	2	
26	☿	,,	30·00	71·1	67·0	61·8	,,	81·0	63·9	·594	6·48	78	7	N.	0	3	1	
27	♃	,,	30·01	73·7	67·0	61·5	,,	77·0	62·1	·558	6·06	67	7	N.W.	1	2	2	Wind at night rose to a gale.
28	♀	,,	29·96	69·0	61·8	59·5	,,	72·8	56·2	·451	4·94	63	18	N.W.	1	2	2	Observed all day without any interruption from clouds.
29	♄	,,	30·00	68·0	59·4	58·2	,,	71·3	52·6	·397	4·32	58	12	N.W.	2	3	2	
30	☉	,,	30·09	70·0	60·1	55·3	,,	74·8	52·5	·395	4·33	53	7	N.	4	2	2	
July																		
1	☾	,,	30·09	71·6	64·0	57·5	2 ,,	72·8	58·3	·487	5·34	63	4	N.W.	9	3	2	
2	♂	,,	30 17	71·2	63·9	55·8	,,	73·5	58·4	·489	5·35	64	2	N.W.	6	3	2	
3	☿	,,	30·20	72·6	65·0	59·8	,,	77·5	59·3	·507	5·48	62	2	N.W.	3	3	1	
4	♃	,,	30·09	75·0	65·2	62·0	,,	87·0	58·1	·485	5·26	55	1	N.W.	0	2	1	
5	♀	,,	30·05	77·8	66·0	68·0	,,	87·0	57·8	·480	5·22	50	1	N.W.	0	3	2	
6	♄	,,	30·10	80·1	65·6	68·8	,,	91·3	55·7	·444	4·77	42	1	N.W.	0	3	2	Wind rose during the day, and at night blew strongly from N.W. Clouds over the sky at 7 P.M.
7	☉	,,	30·12	75·6	65·8	65·8	,,	83·0	58·8	·497	5·38	55	12	N.	0	3	2	

PART V.—STEPS OF SPECTROSCOPY ACCORDING TO INCREASING TEMPERATURE AS COLLECTED DIRECTLY FROM OBSERVATIONS. Referred to in Part II., pp. 289–291.

SPECTRUM PLACE.			STEP 1. TELLURIC-LINES below Freezing.	STEP 2. ColourEdges in Warmed Chamber.	STEP 3. FLAME LINES.		STEP 4. Vacuum Tubes with 1 Inch Sparks.		STEP 5. CHEMICAL LINES with 2 Inch Sparks.		STEP 6. CHEMICAL LINES with 6 to 10 Inch Condenser Sparks.		
Part.	Colour.	WAVE-NUMBER per BRITISH INCH.	CHIEF ONES.	ALL.	Chief Ones.	ALL.	Chief Ones.	ALL.	Chief Ones.	ALL.	Chief Ones.	ALL.	
RED-END.	Ultra-Red.	25000 to 26000		0									RED-END.
		26 27		7									
		27 28		2									
		28 29		1									
		29000 30000		12									
	Crimson-Red.	30000 to 31000		15		0							
		31 32		5		1							
		32 33	1	7	2	2		1		1		1	
		33 34	12	25	1	1		1		1		1	
		34000 35000	14	62	0	0		4		0		0	
	RED.	35000 to 36000	15	25	0	1		5		0		1	
		36 37	20	25	0	1		7		5		5	
		37 38	0	27	2	8		6	2	9	1	26	
	Scarlet.	38 39	10	23	0	9	3	6	2	16	2	34	
	Orange.	39000 40000	3	22	1	18	0	4	1	27	12	69	
MIDDLE OF SPECTRUM.	Amber.	40000 to 41000	6	20	5	18	0	7	3	32	9	79	MIDDLE OF SPECTRUM.
		41 42	3	23	3	19	3	8	8	50	23	123	
		42 43	11	32	1	20	1	7	8	41	19	111	
	Yellow.	43 44	10	75	2	19	1	9	9	39	20	107	
		44000 45000	4	30	0	15	2	8	6	42	22	101	
	CITRON.	45000 to 46000	0	18	5	22	4	11	6	54	30	160	
		46 47	0	22	2	35	1	7	6	48	27	159	
	Green.	47 48	0	15	6	23	2	13	9	62	26	158	
		48 49	0	17	6	25	1	15	12	63	28	172	
		49000 50000	0	17	0	24	1	4	14	66	20	142	
	Glaucous.	50000 to 51000	3	17	0	16	1	7	9	55	18	133	
		51 52	0	16	0	12	0	4	2	45	14	107	
		52 53	2	13	0	11	3	6	8	45	22	116	
		53 54	2	15	1	10	1	6	6	45	24	118	
		54000 55000	0	13	0	8	1	9	1	33	19	91	
VIOLET-END.	Blue.	55000 to 56000		7	3	9	1	7	4	38	18	97	VIOLET-END.
		56 57		18	1	12	1	8	5	40	21	111	
	Indigo.	57 58		11	0	6	1	8	3	38	19	95	
	VIOLET.	58 59		22	2	9	2	10	3	30	17	87	
		59000 60000		11	0	7	2	8	5	42	19	106	
	Lavender.	60000 to 61000		19	3	6	2	7	2	24	8	72	
		61 62		19		2	2	8	1	20	4	55	
		62 63		18		1	1	6	1	25	4	33	
		63 64		15				2		8	0	8	
		64000 65000		9				1		4	2	7	
	Gray.	65000 to 66000		1									
		66 67											
		67 68											
		68 69											
		69000 to 70000											
		Totals, =	116	741	46	370	37	220	136	1048	448	2685	

STEPS OF SPECTROSCOPY ACCORDING TO INCREASING TEMPERATURE, REDUCED TO A UNIFORM TOTAL OF 1000 FOR EACH KIND.

SPECTRUM-PLACE.			STEP 1. TELLURIC-LINES below Freezing.	STEP 2. COLOUR-edges in Warmed Chamber.	STEP 3. FLAME-LINES.			STEP 4. Vacuum Tubes with 1 inch Sparks.			STEP 5. CHEMICAL LINES, with 2 inch Sparks.			STEP 6. CHEMICAL LINES, with 6 to 10 inch Condenser Sparks.			
Part.	Colour.	WAVE-NUMBER per British Inch.	CHIEF ONES.	ALL.	Chief Ones.	ALL.	Mean	Chief Lines	ALL.	Mean	Chief Ones.	ALL.	Mean	Chief Ones.	ALL.	Mean	
RED-END.	Ultra-Red.	25000 to 26000		0													RED-END.
		26 27		9													
		27 28		3													
		28 29		1													
		29000 30000		16													
	Crimson-Red.	30000 to 31000		20		0	0										
		31 32		7		3	1										
		32 33	9	9	43	5	24		4	2		1	1		0	0	
		33 34	103	34	22	3	12		4	2		1	1		0	0	
		34000 35000	120	83	0	0	0		18	9		0	0		0	0	
	RED.	35000 to 36000	129	33	0	3	1		22	11		0	0		0	0	
		36 37	173	33	0	3	1		31	16		4	4		2	1	
	Scarlet.	37 38	0	36	43	21	32		27	14	15	9	12	2	10	6	
		38 39	87	31	0	23	12	78	27	52	15	15	15	4	13	8	
	Orange.	39000 40000	25	30	22	47	34	0	18	9	7	26	16	27	26	26	
MIDDLE OF SPECTRUM.	Amber.	40000 to 41000	51	27	109	47	78	0	32	16	22	31	26	21	29	24	MIDDLE OF SPECTRUM.
		41 42	25	31	65	49	57	78	36	57	59	48	54	51	46	48	
		42 43	94	43	22	52	37	27	32	30	59	39	49	42	41	42	
	Yellow.	43 44	87	101	43	49	46	27	40	34	66	37	52	45	40	42	
		44000 45000	34	41	0	39	20	54	36	45	44	40	42	59	38	44	
	CITRON.	45000 46000	0	24	109	57	83	104	50	77	44	52	48	67	60	64	
		46 47	0	30	43	91	67	27	32	30	44	46	45	60	59	60	
	Green.	47 48	0	18	130	60	95	54	59	56	66	59	62	58	59	58	
		48 49	0	22	130	65	98	27	68	48	88	60	74	62	64	63	
		49000 50000	0	22	0	62	31	27	18	22	103	63	83	45	53	49	
	Glaucous.	50000 51000	25	22	0	42	21	27	32	30	66	52	59	40	49	44	
		51 52	0	21	0	31	16	0	18	9	15	43	29	31	40	36	
		52 53	17	18	0	29	14	78	27	52	59	43	51	49	43	45	
		53 54	17	20	22	26	24	27	27	27	44	43	44	54	44	49	
		54000 55000	0	18	0	21	10	27	40	34	7	31	19	42	34	38	
VIOLET-END.	Blue.	55000 to 56000		9	65	23	44	27	32	30	29	36	32	40	36	38	VIOLET-END.
		56 57		24	22	31	27	27	36	32	37	38	38	47	41	44	
	Indigo.	57 58		15	0	16	8	27	36	32	22	36	29	42	35	38	
	VIOLET.	58 59		30	43	23	33	54	45	50	22	29	26	38	32	35	
		59000 60000		15	0	18	9	54	36	45	37	40	38	42	39	40	
	Lavender.	60000 to 61000		26	65	16	40	54	32	43	15	23	19	18	27	22	
		61 62		26		5	2	54	36	45	7	19	13	9	20	14	
		62 63		24		3	2	27	27	27	7	24	16	9	12	10	
		63 64		20					9	4		8	4	0	3	2	
		64000 65000		12					4	2		4	2	4	3	4	
	Gray.	65000 to 66000		1													
		66 67															
		67 68															
		68 69															
		69000 70000															

THE SOLAR STEP IN SPECTROSCOPY, TOUCHING POSSIBLE SOLAR SURFACE TEMPERATURE.

SPECTRUM PLACE.			ANGSTROM'S NORMAL SOLAR SPECTRUM AS OBSERVED.		LISBON SOLAR SPECTRUM AS OBSERVED.			ANGSTROM'S N.S.S., Reduced to a Uniform Total of 1000.			LISBON S.S. Reduced to a Uniform Total of 1000.		
Part.	Colour.	WAVE-NUMBER per British Inch.	Chief Lines.	All.	Chief Lines	All.		Chief Lines	All.	Mean	Chief Lines	All.	Mean
RED-END.		25000 to 26000					**RED-END.**						
		26 27											
	Ultra-Red.	27 28											
		28 29											
		29000 30000			1	3					4	1	2
		30000 to 31000	Supplied (1)	Supplied (3)	1	5					4	2	3
		31 32	Do. (1)	Do. (10)	2	9					9	4	6
	Crimson-Red.	32 33	Do. ( )	Do. (3)	0	3					0	1	0
		33 34	Do. (7)	Do. (30)	6	34					27	17	22
		34000 35000	0	16	0	28		0	11	6	0	14	7
	RED.	35000 to 36000	0	12	0	50		0	9	4	0	24	12
		36 37	1	22	6	35		5	16	10	27	17	22
	Scarlet.	37 38	1	10	0	22		5	7	6	0	11	6
		38 39	3	21	1	33		14	15	14	4	16	10
	Orange.	39000 40000	8	39	0	38		39	28	34	0	19	10
MIDDLE OF SPECTRUM.		40000 to 41000	7	55	2	51	MIDDLE OF SPECTRUM.	34	39	36	9	25	17
	Amber.	41 42	10	53	0	51		49	38	44	0	25	12
		42 43	6	30	2	51		29	21	25	9	25	17
		43 44	5	41	3	53		24	29	26	14	26	20
	Yellow.	44000 45000	5	51	3	57		24	36	30	14	28	21
	CITRON.	45000 to 46000	11	51	3	55		53	36	44	14	27	21
		46 47	11	50	8	55		53	36	44	36	27	32
		47 48	8	54	10	64		39	38	38	45	32	38
	Green.	48 49	15	59	8	78		73	42	58	36	39	38
		49000 50000	9	57	8	82		44	40	42	36	40	38
		50000 to 51000	8	56	5	92		39	40	40	22	46	34
		51 52	6	51	5	78		29	36	32	22	39	30
	Glaucous.	52 53	8	40	5	82		39	28	34	22	41	32
		53 54	5	58	5	72		24	41	32	22	36	29
		54000 55000	7	48	8	86		34	34	34	36	42	39
VIOLET-END.	Blue.	55000 to 56000	7	58	5	73	**VIOLET-END.**	34	41	38	22	36	29
		56 57	8	60	6	69		39	43	41	27	34	30
	Indigo.	57 58	5	53	16	86		24	38	31	72	42	57
		58 59	4	64	10	82		19	45	32	45	40	42
	VIOLET.	59000 60000	5	85	20	96		24	60	42	90	48	69
		60000 to 61000	6	58	16	88		29	41	35	72	44	58
		61 62	7	41	16	74		34	29	32	72	37	54
	Lavender.	62 63	6	35	22	80		29	25	27	99	40	69
		63 64	6	24	6	80		29	17	23	27	40	34
		64000 65000	8	12	13	24		39	9	24	59	12	36
		65000 to 66000	0	0	0	0		0	0	0	0	0	0
		66 67											
	Gray.	67 68											
		68 69											
		69000 70000											
		Totals, .	205	1410	222	2019							

APPENDIX.

While the above paper was passing through the Press, I have had the honour of receiving from Prof. S. P. Langley, of the Alleghaney Observatory, United States, North America, a copy of his double pamphlet on, 1st, the Solar Spectral lines, A and B, Oct. 7, 1878; and 2nd, the Temperature of the Sun's visible surface, Oct. 9, 1878; printed subsequently in the Proceedings of the American Academy.

Prof. Langley has, if I may presume so to say, a speciality for doing whatever he has to do, most thoroughly; so that his one drawing of a Sun-spot a few years ago, copied into Padre Secchi's classical work on the Sun, outweighs at once the legions of drawings by almost all the other observers put together; and in the present instance, his labours have not been of a less *excelsior* kind.

Remembering, as I do, the sudden delight with which my Wife and I recognised the exquisite duplicity residing in the lines of great B and its preliminary band, when we first saw them in June, 1878,—I must congratulate Prof. Langley on having been able to detect a similar duplicity in the lines composing the preliminary band of great A. I can believe it too, most completely, though I did not see it so myself; for the Dispersion at that point of the spectrum with the "grating" he used (the most magnificent example yet given forth of Mr Rutherford's unequalled mechanics, containing 17296 lines *per* inch, over a surface 1·75 inch square), must have been some three times greater, and much better defined too, than anything which could be got out of the small compound prisms to which I was restricted in my examinations of A and its band of lines in 1877. But the larger prisms which I used in 1878 on the B line, enabled me both to see and measure, not only the duplicity of the lines of B's preliminary band, but of those of its attached band as well; a higher and more refined kind of duplicity, which does not seem to have been noted yet by any one else, and may be the subject of further observation.

Next, with regard to the Temperature of the Sun's photospheric surface, Prof. Langley's mode of proceeding was so different from mine,—that the very similar, though more positively and numerically expressed, conclusions which he arrives at finally, are a most satisfactory confirmation on a point of exceeding difficulty, but of infinite importance to man and all his science.

Prof. Langley first calls attention to the extravagant differences of result among many of the best scientists, and especially to their later lowerings of the Sun's surface temperature,—so that while, a few years ago, that all important quantity was announced by,—

Sir John Herschel, ... = 9,000,000° Fahr.
And by Mr Ericssen, ... = 4,000,000 „
The late Padre Secchi made it only, . . . = 239,000 „
Sir William Thomson and others, from . . = 108,000 „
down to . . = 54,000 „
Several French observers, ... = 4,500 „
And lastly, M. Violle, of Grenoble, only . . = 2,800 „

the latter figure being lower than that for melting platinum.

The Alleghaney Astronomer determining therefore to make the most direct and practically convincing experiment possible,—sought out the largest available surface of the most intensely heated material to be had upon this earth; and this he found in Bessemer's steel converter; whose contents offer a surface of several square feet, of a proved temperature above that of melted platinum; and of so intense a brilliancy, that ordinary cast iron, though proverbially bright, looked like a stream of dark coffee when poured into it. The radiation then of this terrible converter, flinging showers of burning particles around it, was then compared by a differential instrument immediately with the Sun; and though the attendant circumstances of the observation were always in favour of the Converter, and against the Sun, yet the latter was ever found vastly the superior.

Indeed the Solar heat-radiation, so far from being comparable, as recently taught in many places, to furnace heat, "is," says Professor LANGLEY, "even at a *minimum*, at least 100 times the heat-radiation from melted platinum, area for area; and may be much more." That is, the temperature of the Sun's general photospheric surface must be at least above, and probably very much above, 300,000° Fahr.; or if we take the light-radiations, which he considers a more trustworthy observation, the Solar superficial temperature, at every point of its area, must amount, on a mean, to more nearly 15,000,000° Fahr.!

Wherefore, he concludes, that everything "seems to point to the use of the highest attainable terrestrial temperatures (*ex. gr.* that of the electric light) in comparisons, as the safest line for future investigations." P. S.

ERRATA.

Page 298, Line 39 112, for *Barium* read *Iron.*
Page 299, Line 39 264, for *Iron* read *Calcium.*
Page 312, Group 50 411, add *but also Titanium and Iron lines.*
Page 321, Group 56 022, for *Iron* read *Iron and Calcium.*
Page 324, Group 57 728, for *Nickel* read *Nickel and Iron.*
Page 325, Group 58 139, for *Iron* read *Iron and Chromium.*

X.—*On the Structure and Affinities of the* Platysomidæ. By RAMSAY H. TRAQUAIR, M.D., F.R.S.E., Keeper of the Natural History Collections in the Museum of Science and Art, Edinburgh. (Plates III.-VI.)

(Read 5th May 1879.)

INTRODUCTION.

The genera, which I at present include under the family term *Platysomidæ*, are the following:—

1. *Eurynotus,* Agassiz.
2. *Benedenius,* Traquair.
3. *Mesolepis,* Young.
4. *Eurysomus,* Young.
5. *Wardichthys,* Traquair.
6. *Cheirodus,* M'Coy.
7. *Platysomus,* Agassiz.

Eurynotus and *Platysomus* (incl. *Eurysomus*) were classified by AGASSIZ in his Lepidoid family of Ganoids, the former genus forming in his opinion a transition between the latter and *Amblypterus.*[*] By GIEBEL, *Eurynotus* and *Platysomus* were included in his "Heterocerci Monopterygii," along with the Palæoniscoid genera known at that time, and unfortunately also along with certain other very heterogeneous elements (*Eugnathus, Conodus, Megalichthys*).[†] By QUENSTEDT *Platysomus* was also placed among the Heterocercal Ganoids, immediately after *Palæoniscus, Amblypterus,* and *Pygopterus.*[‡]

But already, before the appearance of QUENSTEDT'S "Handbuch," Sir PHILIP GREY-EGERTON [§] advocated the removal of the genus *Platysomus* to the family Pycnodontidæ on the following grounds:—The mandible of a specimen of *Platysomus macrurus,* Agassiz, from Ferry Hill, showed two rows of peculiar teeth with flattened crowns, supported on constricted necks, the dentary element of the jaw on which they were placed being also a "dense triangular bone, very similar to the Pycnodont jaws found at Stonesfield and elsewhere."

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[*] Poissons Fossiles, vol. ii. pt. 1, p. 153.

[†] Fauna der Vorwelt, vol. i. pt. 3, Leipzig, 1848.

[‡] Handbuch der Petrefactenkunde, Tübingen, 1852.

[§] On the Affinities of the Genus *Platysomus,* "Qu. Journ. Geol. Soc., London," v. (1849), p. 329-332.

Münster's genus *Globulodus,* founded upon rounded pedunculated teeth from the Kupferschiefer, was cancelled, and merged in *Platysomus,* Agassiz having also previously expressed a suspicion that these teeth appertained to the last named genus. Sir Philip also considered his views as to the Pycnodont nature of *Platysomus* to be completely corroborated by the form and arrangement of the scales. For he had made the important discovery that the so-called "dermal ribs" of the Pycnodonts were in reality nothing more than thickenings of the anterior margins of the scales, obliquely sliced off above and below for articulation with the adjoining scales of the same dorso-ventral band. Pointing out that a similar conformation was to be found in the high and narrow scales of *Platysomus,* he maintained that the squamation as well as the dentition justified the incorporation of that genus with the Pycnodont family.

In this view Agassiz concurred, and in a letter quoted by Sir Philip says, that the "teeth are conclusive evidence for placing *Platysomus* with the Pycnodonts." It must at the same time be remembered that Agassiz himself had previously stated that the jaws of *Platysomus* were armed with "petites dents en brosse tres-pointues," and that in *Platysomus gibbosus* "on aperçoit quelques petites dents au bord du maxillaire supérieur."[*] And with regard to *Globulodus,* he had also, besides suspecting its identity with *Platysomus,* expressed himself as follows with regard to its supposed Pycnodont affinities—"Nous connaissons du moins dans la famille des Lepidoides les genres *Tetragonolepis* et *Dapedius,* dont les dents également petites sont plus on moins renflées au sommet; *mais je ne connais point de Pycnodontes qui aient des dents pédiculées comme celles du genre Globulodus.*"[†]

As regards *Eurynotus,* Sir Philip Grey-Egerton announced in the following year[‡] that it also had obtuse teeth, having received from Hugh Miller a letter on the subject, with a cast of a specimen from Fifeshire, showing some rounded palatal teeth *in situ.* He, however, hesitated to remove *Eurynotus* to the Pycnodont family, and stated regarding its dentition—"These" (the teeth) "at first sight would seem to indicate a Pycnodont, but a comparison of the dentition of this family with other fishes, having blunt rounded teeth, especially with *Lepidotus* and *Tetragonolepis,* shows that there is so great a difference in the arrangement of the teeth in the two families, that even without the test of microscopic examination, the true affinities of the fish can be determined." Accordingly Sir Philip retained *Eurynotus* as a Heterocercal Lepidoid, admitting, however, that its dentition, as well as that of *Amblypterus macropterus* (*Rhabdolepis,* Troschel), as ascertained by Goldfuss, invalidated the definition of that family given by Agassiz.

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[*] Poissons Fossiles, vol. ii. pt. 1, p. 165.

[†] *Ib.* p. 203.

[‡] Qu. Journ. Geol. Soc. London, vi. (1850).

These views as to the position of *Platysomus* met with very considerable acceptance; accordingly we find, in the systematic works of GEINITZ,[*] PICTET,[†] and M'COY,[‡] this genus included in the family Pycnodontidæ.

Nevertheless there were some dissentient voices. VOGT, in his classification of the Ganoids, published in 1852,[§] continued to associate *Platysomus,* as well as *Eurynotus,* with the *Palæonisci,* placing them together in the subfamily "*Palæonisciden*" of the family *Monosticha.* HECKEL[||] and WAGNER,[¶] both of whom had laboriously studied the Pycnodontidæ, also declined to admit into that family either *Platysomus* or *Tetragonolepis* (*Pleurolepis,* Quenstedt), the latter genus having also, on account of its scales, been subsequently brought by Sir PHILIP GREY-EGERTON under the same category. Their objections as regards *Platysomus* were chiefly founded upon its heterocercal tail, fulcrated fins, and non-possession of the peculiar premandibular bone, or "Vorkiefer" of the Pycnodonts. With regard to the teeth of *Platysomus macrurus* (*Eurysomus,* Young), and those of *Globulodus,* Dr WAGNER recalled attention to the fact that AGASSIZ originally hesitated to recognise the latter as Pycnodont, adding,—"Ich setze hinzu dass die Zähne von *Platysomus* die grösste Aehnlichkeit mit denen des *Lepidotus* zeigen, also *keinesweges auf die Pycnodonten hinweisen,*" stating also that we knew nothing of the condition of the upper jaw in *Platysomus.* He admitted that the form of the body and of the scales were in favour of Pycnodont affinities; the other characters were, however, either not exclusive, or in contradiction with the peculiarities of the Pycnodonts. Dismembering the old "Lepidoidei" of AGASSIZ, Dr WAGNER now proposed to constitute a new family of "Stylodontes," which should include besides *Platysomus,* also the genera *Pleurolepis,* Quenst. (=*Tetragonolepis,* Bronn, Egerton),*Homœlepis,* Wagner, *Heterostrophus,* Wagner, *Dapedius,* De la Beche, and *Tetragonolepis,* Agassiz (=*Æchmodus,* Egerton). We shall see in the sequel that the association by Wagner of *Platysomus* with those other genera is just as unnatural as the classification which he himself wrote to oppose.

In 1866, however, Professor YOUNG,[**] in a well-known paper, declined to accept the peculiar dentition of *Platysomus macrurus* as characteristic of all the species which had been referred to that genus, and recalled attention to the "dents en brosse," mentioned by AGASSIZ in his generic definition, which he said "are not Pycnodont, but Lepidoid (=Lepidosteid)." Minutely describing the structure, of a small Carboniferous fish, which he referred to the *Platysomus parvulus* of AGASSIZ, he stated that it also had its jaws "armed with slender conical teeth,"

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[*] Dyas, Leipzig, 1861, p. 8.

[†] Traité de Palæontologie, 2d ed., 1854, vol. ii. p. 208.

[‡] British Palæozoic Fossils, p. 614.

[§] Zoologische Briefe, vol. ii., Frankfurt, 1852.

[||] Beiträge zur Kenntniss der fossilen Fische Oesterreichs, Denkschr. Ac. Wien. xi. 1856.

[¶] Münchener gelehrte Anzeigen., Bd. L., 1860, pp. 80–99.

[**] On the Affinities of *Platysomus* and Allied Genera, "Qu. Journ. Geol. Soc." 1866.

and accordingly he separated *Platysomus macrurus* as the type of a distinct genus *Eurysomus.* More than this, he described two entirely new though closely allied genera, *Amphicentrum* and *Mesolepis,* in the former of which the dentition is entirely peculiar, while in the latter the teeth somewhat resemble those of *Eurysomus,* consisting of blunted cones with constricted necks. Though not correct in all his osteological details, Professor YOUNG clearly showed that these genera, in spite of the differences in their dentition, are naturally related to each other, and that *Eurynotus* also cannot be disassociated from them, notwithstanding the more palæoniscoid aspect of its scales. Unable to include these forms *in* the Pycnodontidæ proper, he proposed to class them, *along with* that family, in a new "suborder," which should be equivalent to the suborders Crossopterygidæ and Lepidosteidæ, established a few years previously by Professor HUXLEY. To this suborder he gave the name "Lepidopleuridæ," its principal, and indeed only tangible character being the mode of articulation of the scales "by strong ribs traversing their anterior margin internally," a character nevertheless absent in *Eurynotus.* According to Dr YOUNG, this suborder included five families which he tabulated as below :—

I.—VENTRAL FIN WANTING.

PLATYSOMIDÆ.—Teeth uniserial, conical, sharp. Palate bones edentulous. —*Platysomus,* Agassiz, *partim.*

AMPHICENTRIDÆ.—Dorsal and ventral margins sharply acuminated. Teeth in the form of tuberculated plates on the maxillary, mandibular, and palato-vomerine bones. Premaxillary edentulous.—*Amphicentrum.*

EURYSOMIDÆ.—Teeth in the form of blunted cones on a peduncle with a constricted neck.—*Eurysomus* (=*Platysomus,* Agassiz, *partim*).

II.—VENTRAL FIN PRESENT.

MESOLEPIDÆ.—Teeth similar to those of Eurysomus.—*Mesolepis,* n. g.; *Eurynotus,* Agassiz.

PYCNODONTIDÆ.—Teeth oval, hemispherical, or, if elongate, blunted cones.— *Pycnodus, Mesodon, Gyrodus,* &c. (except the Labroid forms of Cocchi).

Tetragonolepis is here excluded, as its place "is undoubtedly among the Lepidosteidæ."

Professor YOUNG's views have in their turn met with very general adoption so far as the institution of the suborder Lepidopleuridæ is concerned. Dr LÜTKEN, for instance, in his excellent treatise on the "Limits and Classification of the Ganoids," has accepted the Lepidopleuridæ, but with this modification that the genus *Tetragonolepis* of Bronn and Egerton, rejected by Dr Young as being a true Lepidosteid form, is introduced as the type of the family "*Pleurolepidæ*," while the four families into which the last-named author divided the palæozoic heterocercal forms are merged into one,—that of the "*Platysomi.*" To the Pleurolepidæ, Dr Lütken conceives it possible that the imperfectly known *Cleithrolepis* of Egerton may belong; while of *Eurynotus* he says that perhaps it is "a palæozoic, heterocercal Stylodont or Sphærodont." Likewise, in Professor Victor Carus's "Handbuch der Zoologie,"[*] the Lepidopleuridæ are accepted and divided into the three families of *Platysomidæ*, *Pleurolepidæ*, and *Pycnodontidæ*, *Eurynotus* being, however, retained in the first.

More recently, however, Professor E. D. Cope[†] has reverted to the plan of placing *Platysomus* in one family with *Dapedius* and *Tetragonolepis*, for which he adopts the term "Dapediidæ" in place of Wagner's "Stylodontes." *Eurynotus*, however, he places in the family "Lepidotidæ," along with *Lepidotus*, *Pholidophorus*, &c., a group which he renders still more heterogeneous by the addition to it of *Amblypterus*, *Palæoniscus*, and *Cosmolepis*. Nothing is said regarding *Amphicentrum* and *Mesolepis*, and on the whole this classification can hardly be considered as an improvement on that of Professor Young, of whose work the author seems to take no cognisance.

That the palæozoic forms enumerated on the first page of this memoir constitute a connected series is undeniable, and considering the small number of genera, it seems convenient to follow Dr Lütken and Professor Carus in uniting them in one family group. I have already expressed my opinion[‡] that these fishes have little in common with the Pycnodonts, while they are intimately allied to the Palæoniscidæ, and that the suborder "Lepidopleuridæ" must be abandoned,—to follow up this idea more in detail is the object of the present paper. I shall therefore first review the structural features of the Platysomidæ, genus by genus, and from the facts thus acquired endeavour, in conclusion, to justify my views as to their real position, and as to the validity, or not, of the suborder established by Professor Young.

To those who have kindly aided me by the loan of specimens of this group my best thanks are due, especially to Mr Ward of Longton, without the use of whose magnificent collection of carboniferous fishes I should not have been able to pursue the investigation far. I am also indebted to the Earl of Enniskillen, Sir Philip Grey-Egerton, Professor Huxley, Professor Geikie, Professor Hughes, Mr William Davies of the British Museum, Dr Rankin of Carluke, Mr Binney of Manchester, and Mr Plant of Salford for much valuable assistance.

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[*] Bd. i. 2te Hälfte, Leipzig, 1875.

[†] Proc. Am. Phil. Soc., May 20, 1877.

[‡] Carboniferous Ganoid Fishes, part i. *Palæoniscidæ*, p. 41, "Mem. Palæontographical Society," 1877.

STRUCTURE OF THE PLATYSOMIDÆ.

Before entering on the structure of the various genera, I must explain that the cranial roof bones of the Platysomidæ, being evidently, like those of the Palæoniscidæ, entirely superficial or dermal in their nature, the terms "anterior" and "posterior frontal" are not used to designate bones absolutely identical with those so named in the Cuvierian nomenclature, for which I prefer Mr PARKER's terms, "ectoethmoidal" and "sphenotic." The opercular bones being in this group also very similarly conformed to those in the Palæoniscidæ, I shall, in accordance with the views expressed in my account of the last-named family, term that plate "interoperculum," which has been hitherto known as "suboperculum."

GENUS I. *Eurynotus,* Agassiz, 1835.

Plectrolepis, Egerton, 1850 (Agassiz ?).
Platysomus, Agassiz, *pars* (M.S.)
Platysomus, De Koninck, *pars,* 1878.

History.—*Eurynotus* is mentioned by AGASSIZ in the report of the meeting of the British Association at Edinburgh in 1834, and also by HIBBERT-WARE in the "Proceedings of the Royal Society of Edinburgh" for December 1834, and in his Memoir on the Burdiehouse Limestone, in vol. xiii. of the Transactions of the same Society. Descriptions and figures of *E. crenatus* from Burdiehouse, *E. fimbriatus* from Wardie, and *E. tenuiceps* from Sunderland, Massachusetts, were given by AGASSIZ in 1835,* who considered the genus as "Lepidoid," and intermediate between *Amblypterus* and *Platysomus*—" La forme de son corps et de sa nageoire dorsal le rapproche même davantage des genres à corps plat, tandis que la forme des nageoires paires rapelle le genre Amblypterus." Regarding the teeth, he says that the margin of the inferior maxillary is armed with " plusieurs rangées de dents extremement fines et obtuses," but he seems to have mistaken the maxilla for a suborbital. AGASSIZ's third species, *E. tenuiceps,* from the Triassic beds of North America, was subsequently ascertained by W. C. REDFIELD not to be a *Eurynotus,*† and it is now referred to Sir PHILIP GREY-EGERTON's genus *Ischypterus,* belonging to a totally different family.

In 1850 Sir PHILIP GREY-EGERTON quoted a letter from HUGH MILLER relative to the rounded palatal teeth of *Eurynotus,* having also received a cast of the specimen, but, as we have already seen, he did not consider these teeth as

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* Poissons Fossiles, vol. i. part i. pp. 153–160.

† Short Notices of American Fossil Fishes, "Am. Journ. Sc." xli. 1841.

a sufficient cause for removing it to the Pycnodont family.* The same circumstance is also noted by Professor YOUNG, who mentions another specimen in the British Museum showing the palatal teeth in this genus, whose affinity to *Mesolepis* he fully recognises.†

In 1867 I myself published a description of several of the bones of the head of *Eurynotus*,‡ including the operculars, maxilla, branchiostegal rays and tooth-bearing palatal plate, pointing out the presence of similar rounded teeth also on the edge of the maxilla. The restored figure of the side of the head which I gave at that time is, however, erroneous as regards the form of the snout, which, not having seen any perfect examples, I represented as forming a projection over the mouth similar to that which is characteristic of the Palæoniscidæ; the mandible is also too long and slender. Subsequent examination of a large quantity of additional material has, in other points, confirmed the observations then recorded.

Species.—The species of *Eurynotus* require revision as regards their distinctive characters, but this I must reserve for another occasion. I may, nevertheless, here observe that, in my opinion, the fish in Lord ENNISKILLEN's collection, which Sir PHILIP GREY-EGERTON§ referred to the *Plectrolepis rugosus* of AGASSIZ, is a species of *Eurynotus*, and that the *Platysomus declivus* of AGASSIZ contained in Sir PHILIP's own cabinet, and catalogued by MORRIS,‖ is most undoubtedly a distorted specimen of *Eurynotus crenatus.* For the opportunity of examining both of these specimens I am indebted to the kindness of their distinguished owners.

I am also indebted to the kindness and courtesy of the authorities of the Royal Museum of Natural History in Brussels for the opportunity of examining one of the specimens from the Carboniferous Limestone of Viesville in Belgium, recently described by Professor DE KONINCK under the name of *Platysomus* (?) *insignis.*¶ I find it to be an undoubted *Eurynotus,* and closely allied to *E. crenatus* of AGASSIZ.

Geological Distribution.—So far as investigation has hitherto reached, the genus *Eurynotus* is confined to the Lower division of the Carboniferous formation. In Scotland it ranges from the Wardie shales up to the top of the Carboniferous Limestone series, and is especially abundant in Edinburghshire and Fifeshire; indeed, in the Calciferous Sandstone series of the latter county it seems to form the great majority of all the smaller fishes which the collector

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* On the Ganoidei Heterocerci, "Qu. Journ. Geol. Soc. Lond." vi. 1850.

† On the Affinities of *Platysomus* and Allied Genera, "Qu. Journ. Geol. Soc. Lond." 1866.

‡ Description of *Pygopterus Greenockii*, &c., "Trans. Roy. Soc. Edinb." 1867.

§ Ganoidei Heterocerci, p. 3.

‖ Catalogue of British Fossils, London, 1854, p. 339.

¶ Faune du Calcaire Carbonifère de la Belgique, in "Annales du Musée d'Histoire Naturelle de Belgique," Brussels, 1878, p. 25, pl. iii.

meets with. It occurs also in the west of Scotland, as in the Possil ironstones. No specimens, save those from Belgium mentioned above, have as yet been found in any other country, nor has it in any case occurred above the horizon of the Millstone grit.

Structure.—In *Eurynotus* (Plate III. fig. 1) the body is rather deeply fusiform, the tail very heterocercal, deeply cleft and inequilobate. There are largely developed pectorals and abdominally placed ventrals; the anal is acuminate with a short base, like that of most Palæoniscidæ. But the dorsal fin is very long, extending from opposite the origin of the ventrals as far as the tail pedicle; in front it is high and acuminate, but posteriorly it becomes low and fringe-like.

The structure of the fins is, however, altogether Palæoniscoid. The rays are closely set, their demi-rays strongly imbricating from before backwards, except in the hinder part of the fins, especially in the fringe-like portion of the dorsal and the upper lobe of the caudal, where little imbrication is observable. They are ganoid externally, and articulated throughout; the joints simulating the appearance of small scales. The stronger rays of the anterior parts of the fins dichotomise towards their terminations in the shorter rays; posteriorly, this process creeps up towards their middle. The anterior margins of all the fins are set with prominent fulcra, which form a double row.

The scales have not been quite accurately figured by Agassiz, whose artist (as is too often the case in the plates of the "Poissons Fossiles") has slurred over their salient peculiarities of form. Those of the body are arranged in the usual oblique or slightly sigmoidal dorso-ventral bands. Taking a scale from the front of the flank (Plate III. fig. 2), it is conspicuously higher than broad, though not so much so as in some other genera (*Platysomus, Cheirodus,* &c.). The anterior covered area is of considerable breadth, and marked off by a vertical groove from the exposed one, which is rhomboidal, the acute angles being posterior-superior and anterior-inferior; the posterior margin is denticulated, or rather fimbriated, with fine sharp points, which, however, on some parts of the body, tend to pass into a coarse and prominent denticulation. The pointed articular spine or peg arising from the upper margin is of moderate size, and is quite distinct from the acute and upwardly produced anterior-superior angle of the scale. On the attached surface (fig. 3) a socket corresponding to the articular spine of the scale next below is seen at the lower margin, from which extending upwards to its own spine is an indication of the usual vertical keel. Towards the dorsal and ventral margins the scales become more equilateral, and that is also the case towards the tail, while they become at the same time more obliquely and regularly rhomboidal, and the keel of the attached surface more marked (figs. 5, 6). The scales of the sides of the caudal body-prolongation (figs. 8, 9) are acutely lozenge-shaped, and arranged in very oblique rows, whose direction is from above downwards and forwards; along its upper margin or ridge they are acutely V-shaped and imbricating (fig. 7). The free surface of all the scales is covered by a glittering layer of ganoine, ornamented by scattered punctures passing into short grooves and streaks, the ornament usually fading away as we pass towards the hinder regions of the body.

The shoulder-girdle also is constructed on the same type as in the Palæoniscidæ. I have not obtained a satisfactory view of the plate, which in that family I have considered as post-temporal, but there is a well-marked *supra-clavicular* (*s cl*, fig. 1) obliquely perforated above by the canal of the lateral line; its direction is more vertical than in the Palæoniscidæ. This is followed by a strong clavicle (*cl*), of the same general form as in the last-named group of fishes, to the front of the inferior extremity of which there is articulated an *infra-clavicular* plate (*i. cl*), which is, however, proportionally shorter, while just behind the junction of the supra-clavicular with the clavicle we find a small *post-clavicular* of a narrow semilunar shape.

The line of the top of the head, sloping pretty rapidly downwards and forwards, shows a convexity over the region of the orbit, which has not the remarkably anterior position seen in the Palæoniscidæ, but is placed nearly right over the upper jaw; the snout, too, does not project in the same manner over the front of the mouth. Common as specimens of *Eurynotus* are in the Edinburgh district, I have never yet obtained a specimen giving a proper view of the bones of the cranial shield; two short *parietals* (*pa*) articulating with each other in the middle line, followed by two slightly larger *frontals* (*f*), are all which can be made out with accuracy, owing to the crushed condition of the heads, though I have also seen indications of a squamosal and posterior frontal. The base of the skull is furnished with a powerful parasphenoid; ossifications were doubtless present in its side walls, but cannot be described. The position of the suspensorium is nearly vertical, with perhaps a slight inclination forwards, consequently the gape does not assume quite the enormous extent characteristic of the Palæoniscidæ. The mandible is stout; externally a *dentary* (*d*) and an *angular* element (*ag*) are visible, the former occupying nearly the whole extent of the jaw, and having its upper margin set with small obtuse teeth; internally there is a *splenial*, also dentigerous. The *maxilla* (*mx*, figs. 1, 10, 11, 13, 14), always easily recognisable, is triangular, having two long sides, upper and lower, and a short posterior one, the latter being nearly vertical, with a slight backward inclination, while the upper margin slopes gently downwards and forwards to the bluntly pointed anterior extremity. The lower margin, nearly horizontal in position and very gently convex in contour, shows, seen from the outside (fig. 13), but few evidences of teeth, to get a proper view of which it must be looked at from within (figs. 10, 11, 14). Here it will be seen that a little in front of the posterior-inferior angle of the bone a narrow band of obtuse teeth commences, and extends all the way along the internal aspect of that margin to the anterior extremity. These are at first closely and somewhat irregularly packed together, but as the anterior extremity of the bone is approached they become very small, and tend to be arranged in lines transverse or slightly oblique to the margin. Of the præmaxilla I can say nothing. Of the palato-quadrate apparatus, the only element I have seen is a plate (fig. 12), evidently the representative of the large pterygoid or ectopterygoid of the Palæoniscidæ, which I found lying detached on a slab of shale beside a maxilla (fig. 13) and numerous scales of *Eurynotus;* portions of the same bone, crushed and obscured, are often seen in the heads of entire specimens. It carries a large oval patch of obtuse teeth, this patch showing three slight longitudinal elevations, separated by two corresponding shallow depressions. Of these elevations or ridges, two form the margins of the tooth patch, one of them corresponding with the external margin of the entire bone at this place; the third passes midway between them, and bears the largest teeth. The teeth themselves are all obtuse, often at the first glance suggesting an aggregation of small grains of shot. On examination they are seen to be mostly in the form of short blunt cones, sometimes round in transverse section, or somewhat elliptical, or polygonal from close crowding; on the dentary element of the mandible they are frequently laterally compressed in shape. The base is sometimes, though not always, slightly constricted, and a few slight vertical grooves commonly extend some distance up the sides. Microscopically they consist of dentine, traversed by delicate tubules radiating from a basal pulp cavity, and surmounted by a cap of structureless "enamel" corresponding to, but relatively much larger than, that of the teeth of Palæoniscidæ and many other ganoids. It is apparently the wearing down, by attrition, of this enamel-cap, and the consequent exposure of the softer dentine below, that gives the flattened tops of such worn teeth (fig. 15) the "dimpled" aspect referred to by HUGH MILLER in his letter to Sir PHILIP GREY-EGERTON.

The orbit (*or*) is placed right above the middle of the maxilla, and in its boundary shows at least two conspicuous suborbitals (*s.o*). One of these is a narrow curved bone forming the posterior-inferior part of the orbital margin, and is joined in front by another (the so-called "lachrymal") of a larger size and broader shape, forming the anterior-inferior orbital boundary, and extending along the anterior part of the upper margin of the maxilla towards the snout.

The *operculum* (*op*) is small and of a quadrate shape, with the posterior-superior and anterior-inferior angles rounded off. Immediately below it is another plate (*i.op*), somewhat larger and higher, whose posterior-inferior angle is quite rounded off, while the anterior-inferior comes close behind the quadrate articulation of the mandible. This is evidently the exact homologue of the plate, which in the Palæoniscidæ I have called "*interoperculum*," for reasons given in my memoir on the structure of that family, which interpretation I therefore retain for it in the Platysomidæ. The anterior margins of the operculum and interoperculum form one continuous line, nearly vertical in direction, following that of the hyomandibular, and slightly concave in contour, not angulated at the junction of the two plates, as in the Palæoniscidæ. Now, fitting on to this line in front, and covering the hyomandibular and a portion of the cheek, is a narrow vertical plate (*p. op.*), broadest in the middle and pointed below, and filling in the space between the operculum and interoperculum behind, and the posterior margin of the maxilla and the suborbital chain in front. It is equally evident that this plate is the homologue of that which I have marked "*preoperculum*" in the Palæoniscidæ, though much modified in form by the altered direction and configuration of the hyomandibular.

Succeeding the interoperculum and extending between the rami of the mandible, there is on each side a series of *branchiostegal rays* (*br*) in the form of narrow, slightly curved, imbricating plates, whose exact number I have not in any case been able to ascertain. In front, however, exactly the same arrangement is found in *Eurynotus* as that which prevails in most Palæoniscidæ (*e.g.*, *Palæoniscus, Elonichthys*)—viz., the anterior plate of each lateral series is much broader than the rest, and there is a median lozenge-shaped one behind the symphysis corresponding to the median "jugular" in *Amia*, and in many extinct Lepidosteid forms (*Eugnathus, Dapedius*, &c.).

The exposed surfaces of the bones of the shoulder, and of the exterior of the head of *Eurynotus* are brilliantly ganoid and ornately sculptured, usually with tolerably coarse and prominent corrugations and furrows.

Owing to the great density of the scaly covering, no internal skeleton can be seen in ordinary entire specimens of *Eurynotus*, though numerous scattered ossicles, apparently spinous processes and interspinous bones, may be observed lying among the scales in disjointed examples. But the Belgian specimen of *Eurynotus* figured by De Koninck (*op. cit.* pl. iii. fig. 1*a*), which I have had the privilege of examining, displays in the dorsal region, where the scales of the left side have been removed with the counterpart, a considerable portion of the internal skeleton *in situ*, compressed against the inner surfaces of the scales of the other side of the body. What is here seen of the internal skeleton consists of a set of short neural spines, surmounted, as in the Palæoniscidæ, by two sets of interspinous bones, proximal and distal, those of the distal set being also less numerous than the dorsal fin-rays which they support. As in *Platysomus*, the proximal set of interspinous bones may be observed extending in front of the dorsal fin towards the occiput. These little bones seem to have been overlooked by Professor De Koninck both in his description and figure, but, indeed, very close examination of the specimen is necessary for their detection.

In no specimen has any trace of vertebral bodies been observed, and the extraordinary distortions of form, so common in specimens of this genus, yield additional evidence that the vertebral axis was notochordal.

GENUS II. *Benedenius,* Traquair, 1878.

Palæoniscus, P. J. Van Beneden, 1871.

My distinguished friend, Professor DE KONINCK of Liége, having come to entertain doubts as to the "Palæoniscus de Denée" of Professor VAN BENEDEN[*] being really referable to that genus, did me some time ago the great honour of confiding to me for redescription the unique and valuable specimen of that remarkable fish from the Carboniferous Limestone of Denée in Belgium. As my detailed account of its structure has already appeared in the first part of Professor DE KONINCK'S new great work on the Fauna of the Belgian Carboniferous Limestone,[†] I shall here restrict myself to noting a few points concerning its generic peculiarities and its place in the system.

Benedenius Denéensis, Van Bened. sp. (Plate III. fig. 17), has the body ovoid, with the dorsal and ventral lines pretty evenly arched, the caudal fin powerfully heterocercal and inequilobate. The dorsal fin, shaped much like that of *Eurynotus,* arises, however, as in *Wardichthys,* considerably behind the middle of the arch of the back; its base extends to the tail pedicle. The anal fin is triangular and acuminate, with a short base; the ventrals are placed rather far back; the pectoral is not completely preserved, but appears rather delicate; the fins are strongly fulcrated. The scales are of moderate size, and arranged in the usual oblique dorso-ventral bands, which, beneath the pectoral, turn forwards as in *Mesolepis, Cheirodus,* &c. Those of the flank are not much higher than broad, delicately striated with transverse and oblique ridges; but as they all lie so very closely in position, and none are seen from the internal aspect, it is impossible to get a view of their entire contour or mode of articulation. A row of large and prominent median scales extends from the front of the dorsal fin to midway between that fin and the occiput; the belly between the ventrals and the lower extremity of the shoulder-girdle displays a series of prominent narrow plates, whose long axis are directed downwards and forwards. The shoulder-girdle is conformed as in *Eurynotus.* The suspensorium is nearly vertical, slightly inclining forwards; the orbit is placed right over the middle of the jaw. The operculum is small and square shaped, the interoperculum is much larger and higher, and is followed by a series of branchiostegal rays. The outer aspect of the posterior part of the mandible displays a very peculiar

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[*] Bull. Ac. Roy. Belg. xxxi. 1871, pp. 512–515, plate iv.

[†] *Op. cit.* pp. 14–23, plate ii.

appearance, as if covered by a number of oval imbricating scales,—a similar appearance is seen on some of the branchiostegal rays. Unfortunately no teeth are visible.

The curious form being evidently no *Palæoniscus*, but on the contrary standing out boldly as a hitherto unrecognised genus, I have bestowed upon it a new generic title, in honour of the eminent naturalist who first made it known to the scientific world; and the structure of the head, as seen by the direction of the suspensorium and the position of the orbit, being clearly Platysomid, and in accordance with the disposition of the dorsal fin, I have transferred it to the family under examination. It resembles *Eurynotus* in the body being less deep than in the rest of the family, in the general aspect of the squamation (the singular ventral scales being left out of view) and in the form of the anal fin, but the dorsal has the position of that fin in *Wardichthys*. *Benedenius* may therefore be placed near *Eurynotus* as one of the most palæoniscoid, in general aspect, of the family Platysomidæ.

GENUS III. *Mesolepis*, Young, 1866.

History.—The genus *Mesolepis* was first made known by Professor YOUNG in 1866, in whose original description we find the contour of the body and fins, and, in one species at least, the shape of the teeth correctly recognised: the figure of the scales given by him cannot, however, be said to give an accurate idea of their configuration.

Specimens of *Mesolepis* (*M. Wardi*?), from the "Drumgray" coal shale at Carluke, occur in Dr RANKIN's collection, one of which gives an exquisite view of the mandibular teeth, with their "minie bullet-shaped" crown, elevated on a constricted neck or stalk. Is it not possible that this specimen may represent the *Pododus capitatus*, catalogued by AGASSIZ in his "Tableau general," as a "Sauroid" from the coal strata of the above named locality? Certainly the name is descriptive enough of the peculiar form of the tooth. But as AGASSIZ left no description or figure behind him whereby *Pododus* (and only too many other genera and species) might be identified, YOUNG's name, *Mesolepis*, must be definitely adopted.

Species.—Professor YOUNG has distinguished two species—*M. Wardi*, in which the length of the trunk is nearly twice its greatest depth, and the tail pedicle thick and elongate; and *M. scalaris* (Plate IV. fig. 1), in which the body is more arched dorsally, and the tail pedicle very short and slender.

I am indebted to Mr BINNEY of Manchester, and Mr BERESFORD WRIGHT of Aldercar Hall, Nottinghamshire, for the loan of two specimens of *Mesolepis* from the Dalemoor Rake Ironstone (Lower Coal Measures) of Stanton-by-Dale in Derbyshire, which seem to me to indicate yet another species, which I propose to call *Mesolepis micropterus.* We have in these specimens the deep body and narrow tail pedicle of *M. scalaris* along with a dorsal fin which is proportionally less high and acuminate in front than in that species. The mandibular teeth are exposed in the specimen belonging to Mr BERESFORD WRIGHT, and these, though the fish is in other respects an undoubted *Mesolepis,* are, like the teeth of *Platysomus parvulus,* slender and cylindro-conical in shape, and scarcely dilated above the root.

Geological Distribution.—Mesolepis has hitherto been found only in the Coal Measures or Upper Carboniferous rocks of Great Britain, and seems to be nowhere very abundant as regards number of specimens. The best examples of the genus which I have seen are from North Staffordshire, and are in the collection of Mr WARD of Longton; but it occurs also in the coal-fields of Derbyshire and of Lanarkshire.

Structure.—The body is deeply fusiform, deeper than in *Eurynotus,* less so than in *Platysomus.* The scales of the flank are higher than broad, but as Professor YOUNG has observed, they have not yet assumed the extremely high and narrow aspect seen in *Cheirodus* and *Platysomus.* As usual, the scales become more equilateral towards the dorsal, ventral, and caudal aspects. Taking the external aspect of a scale from the front part of the flank (Plate IV. fig. 2), its marginal covered area is seen to be very narrow; the exposed surface is quadrilateral and slightly rhomboidal, and is ornamented by raised tubercles, frequently running together into sinuous ridges, which are more or less vertical in their direction; from the upper margin, and close to the anterior superior angle, there arises a prominent, flattened, and pointed articular spine, marked externally by one or two furrows converging downwards towards its base. The internal aspect of the scale (fig. 3) is smooth, and presents a vertical keel, close to and parallel with the anterior margin, passing above into the articular spine, and bevelled off below and behind by the anterior margin of the pointed fossette which lodges the spine of the scale next below. It is manifest that these flank-scales are conformed exactly upon the so-called "Lepidopleurid" type, but further back, as for instance opposite the origin of the anal fin, the keel or "scale-rib" tends to pass back toward the middle of the scale, becoming less marked or even obsolete, while the articular spine and corresponding fossette appear upon the middle of the upper and lower margins respectively (figs. 4 and 5). No better instance could be had of the unimportance, as a "subordinal" character at least, of the position upon the scale of these keels or so-called scale-ribs. The scales of the body are arranged in dorso-ventral bands, whose backward obliquity is rather less than in *Eurynotus;* below the root of the pectoral fin the most anterior of these turn a little forwards; the same condition is observed on the back for a little distance behind the occiput. The scales clothing the sides of the caudal body prolongation are small and acutely lozenge-shaped, and arranged in bands directed very obliquely downwards and forwards, this arrangement commencing as usual opposite the lower caudal lobe; the upper margin of the same part is set with large and imbricating V scales.

In general form the head of *Mesolepis* (Plate IV. figs. 1 and 9) resembles very closely that of *Eurynotus*. The sloping contour of the top of the head shows the same rounded prominence over the orbit, below which it slopes still more sharply into the short pointed snout. The bones of the cranial roof are delicately sculptured with ridges and granules; the lines of demarcation between at least some of them may be observed in a specimen belonging to Mr Ward. A pair of well-marked elongated *frontals* (*f*) occupy the top of the buckler, but the boundaries of the plates in the parietal, squamosal, and post-frontal regions are obscured by crushing. The rounded prominence above and in front of the orbit is formed by a narrow median *superethmoidal* plate (*e*), with a broader *anterior frontal* (*a. f*) on each side; the posterior extremity of the former of these is pointed, and received into a notch between the anterior extremities of the frontals, while each of its lateral margins show a rounded notch completed into a small nasal opening (*n*) by the inner margin of the adjacent anterior frontal. The portion of bone forming the snout in front of the last described plates is probably *premaxillary* in its nature.

The line of the suspensorium passes downwards with a slight forward inclination, the *operculum* (*op*) is short, the *interoperculum* (*i. op*) larger and higher; the preoperculum is not exhibited in any specimen I have seen, but a well-developed series of narrow imbricating *branchiostegal rays* or plates (*br*) follows the lower margin of the interoperculum. The *maxilla* (*mx*) resembles that of *Wardichthys* more than that of *Eurynotus;* it is broad behind, pointed in front, the upper margin, sloping downwards and forwards, showing immediately behind the anteriorly directed apex a small rounded expansion; the lower or oral margin is gently convex, and displays no teeth when seen from the outside, nevertheless, on the internal aspect of this margin there are very evident traces of at least *tooth-like* tubercles. The mandible is short and stout, and peculiarly pointed in front; the anterior part of the upper margin of the dentary element is separated off from the rest of the bone by a wide smooth shallow groove, below and behind which the surface is ganoid and sculptured. On the margin thus marked off is seen a set of peculiarly shaped teeth, all of the same size, and apparently in a single row. Each of these teeth, ordinarily and as seen in Plate IV. figs. 6 and 7, consists of a head with bluntly pointed apex, rounded below, and supported by a constricted neck, which again expands so as to form a conical base; but in *M. micropterus* (fig. 8), they are, as I have already stated, cylindro-conical, the apical dilatation and neck-constriction being scarcely if at all marked. I am unable to give any account of the palato-quadrate apparatus, but probably teeth were present on the palate in this as in allied genera. The orbit is placed as in *Eurynotus,* but the circum-orbital plates are badly preserved, a large anterior one (lachrymal) may, however, be clearly seen, as in that genus, over the fore part of the maxilla.

The shoulder girdle presents us with well-marked *post-temporal supra-clavicular, clavicular,* and *infra-clavicular* elements, the three latter, at least, shaped exactly as in *Eurynotus.* The fin-rays are ganoid and sculptured externally, divided by transverse articulations up to their origins, their demi-rays imbricate in the anterior part of each fin, and fulcra are conspicuously present, though these are smaller than in *Eurynotus.* The pectorals are of moderate size, the ventrals well developed and abdominal. The dorsal reminds us strongly of that of *Eurynotus,* commencing opposite the ventrals, and having its anterior margin in the usual condition of expansion of the fin continuous with the line of the back between its origin and the occiput; its anterior rays become very rapidly elongated towards the high and acutely pointed apex, from which they again rapidly fall away posteriorly, so that the hinder two-thirds of the fin is low and fringe-like. The anal is similar in form, but smaller, and its posterior fringe-like part proportionally shorter, the entire length of the base of the fin hardly equalling two-thirds that of the dorsal. The caudal is strongly heterocercal, deeply cleft and inequilobate.

The affinities of *Mesolepis* to *Eurynotus* are clearly seen in the form and position of the dorsal and ventral fins in the powerfully heterocercal and inequilobate caudal, as well as in the form and general osteology of the head. But the scales have now decidedly assumed the Platysomid type, the body is deeper in shape, and the anal fin too has begun to resemble the opposing dorsal, though its base is still considerably shorter. The teeth differ considerably from those of *Eurynotus* in external form, but in such cases where they have a constricted neck they in so far resemble those of *Eurysomus,* a genus long confounded with *Platysomus,* but which has really much more affinity with *Mesolepis.* In *M. micropterus* the form of tooth passes into that which is found in *Platysomus.*

GENUS IV. *Eurysomus,* Young, 1866.

Platysomus (pars), Agassiz, Egerton, et cet. auct.
(?) *Globulodus,* Münster.

The remarkable fish from the English marl slate, designated by AGASSIZ *Platysomus macrurus,* was first figured, though without any name, by Professor SEDGWICK.* At the time, however, of the publication of the "Poissons Fossiles,"

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* Trans. Geol. Soc. Lond., ser. 2, vol. iii. plate xii. figs. 1 and 2.

AGASSIZ had not himself seen a specimen, and he therefore contented himself with the reproduction of SEDGWICK'S figures and a few general remarks as to the leading peculiarities of external form which distinguished it from the associated *Platysomi.*[*] But a much finer specimen, now in the Newcastle Museum, afterwards turned up, in which not only the entire shape of the fish but also the dentition of the lower jaw was preserved, and having been submitted to Sir PHILIP GREY-EGERTON, the mandible was figured by him in the "Quarterly Journal" of the Geological Society,[†] the entire specimen in KING'S "Permian Fossils."[‡] The peculiar form of the teeth as here shown, in which "a circular crown with flattened grinding surface" was "mounted on a pedicle of much less diameter," was attributed by Sir PHILIP to the whole of the species then included under *Platysomus,* and, as we have seen in the introduction, was, along with some other circumstances, especially the form of the scales, considered by him to warrant the removal of *Platysomus,* of which *Globulodus,* Münster, was now considered a synonym, to the family Pycnodontidæ. We have, however, also seen that although AGASSIZ concurred in this view, Professor YOUNG refused to accept the dentition of *Platysomus macrurus* as characteristic also of the true Platysomi, such as *P. gibbosus,* &c., and proposed therefore to institute for the former the new genus *Eurysomus.* With Professor YOUNG, I must certainly agree as regards the distinctness of the genus from *Platysomus,* but at the same time it must be remembered that the resemblance of the teeth of *Eurysomus macrurus* to those of *Globulodus elegans* is so great that were we only quite certain as to the generic identity in this latter case, MÜNSTER'S name would certainly be entitled to preference over Dr YOUNG'S.

Species.—Only one species of *Eurysomus,* viz., *E. macrurus,* Ag. sp., has with certainty been determined. With this, *Platysomus Fuldai* of MÜNSTER, is no doubt generically identical, and the latter has also been merged specifically in "*macrurus*" by GEINITZ.

Geological Distribution.—*Eurysomus* has as yet only occurred in strata of Permian age; in England in the marl slate; in Germany in the Kupferschiefer.

Structure.—I am not in a position to enter minutely into detail regarding the structure of *Eurysomus,* the only specimens which I have seen being that in the Newcastle Museum, and a not very perfect head in the Edinburgh Museum of Science and Art. But no one can look at any of the published figures of the fish without being struck by the evident affinity which it bears to *Mesolepis,* both in its general aspect and in the form and position of its fins. We have a

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[*] Poissons Fossiles, vol. ii. plate i. p. 170; Atlas, vol. ii. plate xviii. figs. 1 and 2.

[†] Vol. v. (1849).

[‡] Mem. Palæontographical Society (1849), plate xxvi. fig. 1.

powerfully heterocercal and inequilobate caudal, a dorsal high in front and becoming fringe-like posteriorly, and an anal similar in form but considerably shorter in the extent of its base. There is also clear evidence of its well-developed and abdominally placed ventrals, a fact also alluded to by Sir PHILIP GREY-EGERTON in his description, so that it is difficult to understand how Dr YOUNG, in his paper on "*Platysomus* and Allied Genera," has described *Eurysomus* as being deficient in that member. The scales seem to be somewhat more strongly keeled than in *Mesolepis*, nevertheless, as Professor YOUNG observes, "the scale character allies it somewhat to the latter genus."

The specimen preserved in the Edinburgh Museum (Plate IV. fig. 10) is deficient as regards the top of the head, nevertheless it shows several details of the greatest importance. There is a large clavicle, similar in shape to that of *Eurynotus* and *Mesolepis*, in front of which is a broad interoperculum, having below it a number of narrow branchiostegal rays. All these bones are ornamented externally by somewhat coarse crenulated wavy ridges passing into tubercles. But the points of greatest interest are those concerning the configuration of the jaws, and here the resemblance to *Mesolepis* is brought out in a manner still more remarkable. In front there is a beak-like portion of bone (*p. mx*), convex and smooth externally, and evidently præmaxillary in its nature; its lower margin is injured, and here the roots of several broken-off teeth are visible. Behind this is the left maxilla (*mx*), which is narrow in front, but broadening out behind in a sort of angular spatulate manner; its broad posterior portion is covered behind by a tubercular ornament. Its upper margin is nearly straight, and slopes gently downwards and forwards; the posterior margin, gently convex, slopes also downwards and forwards, but at a less inclination than the superior one, with which it forms an acute angle above, while below it forms an obtuse angle with the lower margin, which is concave, and passes on to the lower margin of the præmaxilla. No teeth are perceptible in the maxilla when looked at from the outside, but just below the left mandible we get a view of what is clearly the inner aspect of the anterior part of the maxilla of the opposite side (*mx'*), but crushed out of its place, and this displays a row of broken-off tooth-stumps. The mandible (*mn*) is not completely exhibited, being largely overlapped above and behind by the posterior-inferior angle of the maxilla, but its similarity in general form to that of *Mesolepis* is obvious. It is comparatively short and stout, pointed in front and broad behind; a wide oblique shallow groove marks off the dentary margin. The exposed portion of the oral margin bears a row of the large characteristic pedunculated and flattened teeth (fig. 11) so well described by Sir PHILIP GREY-EGERTON. But there is a second or inner row of mandibular teeth, and these would seem to be borne upon the splenial element, judging from the anterior portion of the opposite mandibular ramus (*mn'* fig. 10), which, seen from the internal aspect, is also displayed in the specimen, being displaced and dislocated below the other. The palate is not seen, but we might indeed be tempted to assume that it was as in *Eurynotus* amply supplied with crushing teeth.

It is, therefore, clear that *Eurysomus* is a genus which, far from being identical with *Platysomus,* differs from it, as we shall afterwards see more fully, not only in its dentition, but also in its fins and the form of some of the bones of the head. And precisely in these respects it approaches the carboniferous genus *Mesolepis,* from which it indeed differs principally in the more broadly triangular shape of the mandible and in the shape of the teeth, which, although pedunculated have their crowns much flattened instead of being bluntly conical.

Genus V. *Wardichthys,* Traquair, 1874.

Wardichthys cyclosoma was described by myself in 1874* from a single specimen contained in an ironstone nodule which occurred in the Lower Carboniferous shales (Calciferous Sandstone series) of Newhaven (Wardie), near Edinburgh. It is not a little remarkable, as well as unfortunate, that notwithstanding the large number of ichthyolites which have been collected in this locality, no other specimen of the fish, not even a detached scale, has ever been obtained. The name *Wardichthys* was bestowed upon it, not in reference to the locality, but in honour of my friend Mr Ward of Longton, whose untiring industry in collecting the fishes of his district has contributed so very largely to the advancement of our knowledge of Carboniferous ichthyology.

Structure.—The length of the specimen is three inches, but, as the caudal fin is entirely wanting, its original length was probably about four. The body is nearly circular, the dorsal convexity being, however, considerably greater than the ventral. The head is large, and several of the bones can be distinctly made out (Plate IV. fig. 12). Posteriorly there are two *parietals* (*p*) meeting each other in the middle line, and on the outer side of each is a small *squamosal* (*sq*). In front of the parietals are two more elongated *frontals* (*f*), and again on the outer side of each frontal is a large *posterior frontal* (*p f*), the anterior part of whose outer margin apparently takes part in the posterior-superior boundary of the orbit. In front of this there is another plate (*a. f*) forming in like manner the anterior-superior boundary of the orbit, and which is clearly equivalent to the anterior frontal of *Mesolepis,* &c., but the median superethmoidal cannot be made out. Below this a portion of bone is seen in front of the maxilla, which is probably the præmaxilla. The orbit is thus seen to be placed as in *Mesolepis,* nearly right above the maxilla, but no circum-orbitals are recognisable. A portion of a slender hyomandibular is seen; it

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* Ann. and Mag. Nat. Hist. (4), vol. xv. 1874, p. 262, plate xvi. figs. 1–5.

is somewhat displaced, but from the position of the operculum and the direction of the bones of the shoulder girdle, it is clear that the axis of this element must have been, as in other Platysomids, downwards and slightly forwards. The *operculum* (*op*) is somewhat square-shaped, its posterior-superior angle being rounded, and its straight anterior margin nearly vertical with a slight forward inclination; below it is a larger plate (*i. op*), which is evidently the *interoperculum* a little dislocated from its position; no branchiostegal rays are preserved. The *maxilla* (*mx*) is shaped much as in *Mesolepis*, but the angle between its inferior and posterior margins is very much rounded off, so as to be nearly obsolete; as in that genus, a small laminar projection passes off from its superior margin close behind its bluntly pointed anterior extremity; no teeth are shown. The mandible is not exhibited at all in the specimen. The *post-temporal* element of the shoulder girdle (*p. t*) most nearly resembles that of *Platysomus*, and is a large, somewhat square-shaped plate, with its posterior angles somewhat rounded off, placed right behind the parietal, and apparently in contact above with its fellow of the opposite side. The *supra-clavicular* (*s. cl*) is of considerable size, vertically oblong, rather broad above, where it is obliquely traversed by the lateral slime canal, and narrowing to a point below, where it is in contact with an elongated *clavicle* (*cl*) of the usual Platysomid form. Of the fins, only the dorsal and anal are preserved, and the latter is not in good condition. The dorsal is small, arising considerably behind the middle of the arch of the back, and both in that circumstance and in its shape it resembles the dorsal of *Benedenius*. It is acuminate in front, becoming fringe-like behind, and terminates at the commencement of the narrow tail pedicle; its anterior margin is distinctly fulcrated. But from what is seen of the anal, it is evident that it possessed a more extended base than that of *Benedenius*, and was conformed much like the dorsal. Unfortunately the caudal is not present in specimen, but the analogy of the rest of the structure of the fish leaves no reason for doubt as to its having been heterocercal. The scales of the side of the body (figs. 13 and 14) are high and narrow, and shaped according to the same general type seen in *Mesolepis* or *Platysomus*. The articular spine and internal rib are moderately developed; externally the smooth overlapped marginal area is well defined, while the free surface is ornamented with raised tubercles, which tend to be arranged in lines or to coalesce into short ridges, whose direction is across the scale from before backwards, some downward radiation towards the posterior-inferior angle being often observed at the lower part. As usual, the scales become more equilateral towards the dorsal and ventral margins (fig. 15), and the middle dorsal and ventral lines in front of the dorsal and anal fins are evidently furnished respectively with rows of azygous scales, having backwardly directed spur-shaped points.

It is unfortunate that the dentition of *Wardichthys* is as yet unknown, but its affinity to *Mesolepis* seems pretty clear from the osteology of the head, a resemblance to *Benedenius* being also seen in the small size of the dorsal fin and the backward position of its commencement. But we have now got the deep short body of *Cheirodus* and *Platysomus*, as well as the narrow flank scales of these genera, the scale ornament being, however, very different from that of *Platysomus*, and more resembling what is found in *Cheirodus* and *Mesolepis*.

GENUS VI. *Cheirodus*, M'Coy, 1848.

(?) *Platysomus*, Binney, 1840.

Cheirodus, M'Coy, 1848 (not Pander, 1858); Traquair, 1878.

Amphicentrum, Young, 1866; Hancock and Atthey, 1871; Traquair, 1875.

History.—In 1866 Professor YOUNG[*] instituted the genus *Amphicentrum* for a remarkable Platysomid fish from the North Staffordshire coal-field, which he also distinguished specifically as *A. granulosum.* A second species, *A. striatum*, from the Coal Measures of Northumberland, was in 1871 added by Messrs HANCOCK and ATTHEY.[†]

Professor YOUNG's original description of *A. granulosum* includes a minute account of the osteology of the head, illustrated by a restored outline showing the cranial and facial bones. But in 1875 I published a description of the cranial structure of the same genus, differing in many particulars of great importance from that given by him, especially as regards the determination of those dentigerous bones, which so frequently occur in a detached condition. Since that time the examination of a considerable number of additional specimens from both the North Staffordshire and Lancashire coal-fields has amply confirmed these statements, in which I differed from Professor YOUNG, and has also brought to light a few additional particulars, though there are still some points regarding which some further information is desirable.

But although to Professor YOUNG is undoubtedly due the credit of having first described and figured an entire specimen of this strange and interesting genus, its remains were nevertheless previously not entirely unknown or unpublished. As early as 1841[‡] Mr E. W. BINNEY figured some scales from the Manchester coal-fields as belonging to *Platysomus*, but which, judging

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[*] *Op. cit.*, p. 306.

[†] Nat. Hist. Trans., Northumb. and Durham, vol. iv. 1871, p. 414; also in Ann. and Mag. Nat. Hist., ser. 4, vol. ix. 1872.

[‡] Trans. Manchester Geol. Soc. vol. i. 1841, plate v. figs. 14 and 15.

from the figures, have undoubtedly a much greater resemblance to those of Professor YOUNG's fish. And during a recent visit to the Woodwardian Museum at Cambridge I was surprised to find that the original specimen described by M'COY in 1848[*] as *Cheirodus pes-ranæ,* and considered by him to be the tooth of a Cestraciont allied to *Ceratodus,* then still ranged among the sharks, was in reality nothing more than a mandibular dental plate of the same Platysomid genus. I have, therefore, in a recently published paper,[†] felt compelled by the inexorable law of priority to propose the abolition of "*Amphicentrum,*" however much we may regret the necessity for superseding a name by which the animal in its entirety is so widely known, by one which was originally bestowed upon a mere fragment whose nature its describer did not understand.

Since the discovery of the true position of *Ceratodus, Cheirodus,* M'Coy, has been associated with the Dipnoi, both on account of M'COY's original opinion of its affinities, and because PANDER[‡] not only referred to the same genus the teeth from the Devonian of Russia, which he named *Cheirodus Jerofejewi,* but also merged in it the *Conchodus* of M'COY, which he considered to have been founded on the palatal tooth-plate of a fish generally identical with that whose mandibular one constituted *Cheirodus pes-ranæ.* But it is now clear that *Cheirodus,* Pander, is not = *Cheirodus,* M'Coy, though it is indeed possible that the former may be identical with *Conchodus,* the Dipnoous nature of which is undoubted.

Species.—One unfortunate circumstance connected with the establishment of species upon mere fragments, like M'COY's *Cheirodus pes-ranæ,* consists in the difficulty which we so often experience in satisfactorily deciding as to the identity or non-identity with them of more perfect specimens from other horizons or localities. The difficulty is seriously felt in the case of *Cheirodus,* and although I have, in my paper last referred to, felt inclined "*pes-ranæ,*" M'Coy, and "*granulosus,*" Young, as best kept separate, I must nevertheless own that this view of the case is also open to serious doubt. In any case the retention of Professor YOUNG's specific name seems justifiable, on the ground that M'COY's specimen is hardly sufficient to characterise the species, although, on the other hand, the genus to which it belongs is unmistakable. The only other species known is *C. striatus* of HANCOCK and ATTHEY.

Geological Position.—This is entirely a Carboniferous genus. *C. pes-ranæ,* M'Coy, is from the Carboniferous Limestone of Derbyshire, and Mr W. J. BARKAS has recorded the occurrence of *C. granulosus* in the same formation at Rich-

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[*] Ann. and Mag. Nat. Hist. ser. 2, vol. ii. 1848, pp. 130–131. British Palæozoic Fossils, p. 616, plate 3 *g*, fig. 9.

[†] Ann. and Mag. Nat. Hist., July 1878, pp. 15–17.

[‡] Die Ctenodipterinen des Devonischen Systems, St Petersburg, 1828, pp. 33–37, plate vi. figs. 15–22.

mond, Yorkshire.* *Cheirodus* is, however, chiefly known as a fish of the Coal Measures, in which horizon *C. granulosus* is abundant in North Staffordshire, occurring also in a more fragmentary condition both in Lancashire and in Lanarkshire, while the smaller *C. striatus* has been yielded by the coal strata of Northumberland.

Structure.—The body of *Cheirodus* (Plate V. fig. 1) is deep and rhombic, the dorsal and ventral margins elevated into peaks, of which the dorsal is slightly in advance of the ventral; the tail is completely heterocercal, but not very inequilobate; no ventral fins have been as yet observed, and the pectorals are rarely seen, owing to their having been placed a little higher up than usual on the side of the flattened body, as indicated by the position of their roots, which are always observable behind the lower extremity of the clavicle. The dorsal and anal fins arise immediately behind the respective dorsal and ventral peaks of the body, and extend to the narrow tail pedicle; they are therefore nearly equal, with elongated bases, and fringe-like for the greater part of their extent. Their anterior margins are fulcrated; their rays are numerous, closely set, and closely articulated; the joints being externally ganoid and sculptured. The scales of the body are arranged in bands, which are nearly vertical, with a slight backward obliquity; just below the insertion of the pectoral fin they curve slightly forwards, as in *Mesolepis* and *Benedenius,* turning also slightly backwards just in front of the dorsal and ventral peaks. They are very high and narrow, especially on the flanks, above and below they become lower; while on the caudal body prolongation they are very small, lozenge-shaped, and arranged in oblique rows, whose direction is from above downwards and forwards. The scales are also peculiarly modified on the anterior margins of the dorsal and ventral peaks, where they assume a spur-like appearance, with backwardly directed points; on the upper margin of the caudal body prolongation they have the usual V-shaped aspect and imbricated arrangement. In the body scales the narrow anterior covered area is very distinctly marked off from the sculptured one, which in *C. granulosus* (Plate V. fig. 13) is ornamented with closely set tubercles, which sometimes assume a more or less linear arrangement, while in *C. striatus* they coalesce on the scales of the middle part of the body into actual though somewhat irregular vertical striæ. The articular spine is very strong, its base often extending back along the whole of the upper margin; the vertical rib or keel of the attached surface (fig. 14) is close to the anterior margin, and is very strongly and sharply defined.

The upper contour of the head continues the downward slope of the back in front of the dorsal fin, showing also, as in *Eurynotus* and *Mesolepis,* a slight convexity above and in front of the orbital region, whence its descent to the front of the mouth is more rapid. Most of the cranial roof-bones can be made out

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* Geol. Mag. ser. 2, vol. i. 1874, p. 431.

with great distinctness. There are two parietals (*p*) in contact with each other in the middle line, in advance of which are two somewhat longer frontals (*f*). External to each parietal and the posterior part of the outer margin of the corresponding frontal is a large squamosal (*sq*), in front of which there is a smaller posterior frontal (*p.f*), forming the posterior-superior part of the orbital margin. The anterior-superior part of the orbital boundary is formed by another plate, the anterior frontal (*a.f*), which articulates both with the frontal and posterior frontal, and seems to pass down towards the præmaxilla; but I have not obtained a satisfactory view of the median superethmoidal, which was probably intercalated between the two anterior frontals, nor of the nasal openings, although it is unlikely that these parts differed much from what we have found in *Mesolepis*. The base of the cranium displays a powerfully-developed parasphenoid, but I have not yet seen any specimen in which ossification in the lateral walls could be determined.

The *hyomandibular* (fig. 10, *h. m*) is an elongated bone, whose direction is from above downwards and slightly forwards. Above it shows a large flattened "head," articulated to the side of the cranium below the squamosal; below this head the bone is much constricted, and then assuming a cylindrical form, it gradually expands again in diameter towards its inferior termination, which is situated somewhat above and behind the quadrate articulation. There is no evidence of any symplectic.

A powerful palato-quadrate apparatus (Plate V. figs. 2 and 10) extends forwards from the front of the lower part of the hyomandibular towards the snout. In my previous paper on the skull of *Cheirodus* (*Amphicentrum*), I was inclined to consider this as consisting of one piece, though I likewise stated that it was not certainly so, and that I had observed what seemed to me to be traces of a separate ossification towards its posterior-superior angle. Subsequent investigation has confirmed the latter view of the case, and has brought to light the existence of three elements,—quadrate, pterygoid, and mesopterygoid. The *pterygoid* or palato-pterygoid (*pt.* figs. 2, 3, and 10), which is the largest, has a "body" of an elliptical shape, pointed at both ends, and having on this flat lamina or wing (*y*, fig. 3) projecting upwards along the posterior part of its upper margin. Its outer surface is concave, its inner or oral surface is gently convex, and bears a patch of tolerably prominent shining tubercles, some round, some oval, by which the roof of the mouth is roughened and armed. Its lower margin is convex, and presents two prominent ridges, separated by a groove, but coalescing behind in an acutely V-shaped fashion; each of these ridges, the external of which is more prominent than the other, is armed with a single row of small tuberculo-conical tooth-like projections, rather distantly placed, and varying much in number and degree of prominence in different individuals. With the posterior extremity of the pterygoid is connected a distinct *quadrate* (*qu*, figs. 2 and 10) projecting downwards to articulate with the lower jaw; above which, and extending also along the upper margin of the pterygoid, whose posterior projecting wing it overlaps internally, is another plate (*m.pt.* figs. 2 and 10) of a triangular form, broad behind and narrowing to an acute angle in front, which seems to be the equivalent of the *mesopterygoid* of other fishes. The obvious resemblance which the palato-quadrate apparatus bears to that of the Palæoniscidæ will be noticed further on.*

The mandible is stout and deep, and as regards its constituent elements three may be easily recognised,—the *dentary, splenial,* and *angular;* the articular was doubtless also present, but is not well defined. The *dentary* (*d,* fig 1, 9, and 10) carries, however, no teeth, its upper margin forming a thin sharp edge; its anterior extremity is pointed, prominent, and excavated above, so as to resemble the præmaxillary beak opposed to it. Behind it on the outer surface of the posterior extremity of the jaw is a well-marked *angular* (*ag,* figs. 1 and 10) resembling that of the Palæoniscidæ. The splenial element (*sp,* figs. 6, 7, 8 and 10), covering the inner as well as folding over the upper aspect of the Meckelian cartilage, has its oral surface provided with a patch of enamelled tubercles similar to those of the palate. Its upper margin shows two ridges coalescing posteriorly, and of these the external one is the most prominent, and becomes anteriorly gently convex in its contour, while the other, proceeding in a straight direction, gets lower down as it passes forwards. The inner ridge is also set with a few sharpish dental tubercles, which, however, vary much in prominence in different individuals; they are not found at all in the original of M'Coy's *C. pes-ranæ,* but I fear that this circumstance can hardly be considered as constituting a specific mark, as in many specimens of *C. granulosus* from North Staffordshire they are nearly entirely obsolete.

The contour of the *maxilla* (figs. 4 and 5, *mx* fig. 1) is almost identical with that of the same bone in *Eurynotus,* but its lower margin is thin and sharp, like the corresponding one of the mandibular dentary element, and shows not the slightest trace of teeth of any kind. But on its internal aspect (fig. 4), and just above the edentulous margin, there is a narrow band of small thickly-set flattened and enamelled tubercles, resembling those which we have found to occur in patches upon the inner surface of the pterygoid and splenial bones; this band curving suddenly downwards towards the margin at the junction of the posterior and middle thirds of the bone. The *præmaxillæ* (*p.mx,* fig. 1) are, as Professor Young has described them, a pair of triangular beak-like bones, whose oral edges are sharp but edentulous.

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* Here it is, however, necessary to note that I was formerly inclined to consider the bone, which in the Palæoniscid head corresponds to that which I have above referred to the *mesopterygoid* element, to be *metapterygoid* in its nature (Carboniferous Ganoid Fishes, pt. i. Pal. Soc. 1877, p. 18.)

The *orbit* (*or.*) is placed right over the middle of the mouth; a conspicuous sickle-shaped suborbital bounds it below and behind, while another (the so-called lachrymal), larger and broader, completes it below and in front; besides which there is evidence of a narrow superorbital chain placed along the outer orbital margins of the posterior and anterior frontals, which I rather suspect is continued as a circumorbital ring round its entire circumference. The *opercular* bones and branchiostegal rays are extremely similar in form and relations to those of *Eurynotus.* So likewise are the bones of the *shoulder-girdle,* which include well-marked *infraclaviculars,* but the post-temporal seems to be rather small.

Occasional traces of a pretty well ossified *internal skeleton* may occasionally be seen shining through the dense scaly investment in small specimens. They are too imperfect to admit of detailed description; but so far as they go they seem to indicate that the conditions were pretty similar to what exists in *Platysomus.*

Remarks.—The remarkable genus just described betrays a most singular resemblance to *Eurynotus* in the shape of the cranial bones, while in the form of the body it is more akin to *Platysomus;* and in that of the scales we find the "Lepidopleurid" type carried to an extreme. The dentition is, however, altogether peculiar, and forms a forcible illustration of the small systematic value of the external configuration of these organs; and I also fail to see how, according to Professor YOUNG, "*Amphicentrum* gives the explanation of the arrangement" found in *Pycnodus.*[*]

GENUS VII. *Platysomus,* Agassiz, 1835.

Stromateus, Blainville, Germar.
Uropteryx, Agassiz.

History.—The deep-bodied fishes of the Kupferschiefer were well known to the older German writers in the beginning of last century, such as KNORR and WALCHNER, SCHEUCHZER, MYLIUS, and WOLFART. Palæontology was, however, then in its infancy, and these pioneers of modern science, misled by the broad rhombic shape of these fishes, were content to consider them as petrified turbots, "Rhombus," or in German, "Meerbütt," "Platteiss," "Scholle"). Specially worthy of note is the excellent figure given by WOLFART ("Historia Naturalis Hassiæ inferioris," pt. i. tab. xiii.) of a "*Rhombus major diluvianus*" (*Platysomus rhombus,* Agassiz), in which the general form of the body, of the scales, and of the deeply-cleft heterocercal tail, the latter part being certainly very unlike the caudal fin of a *Rhombus,* are well brought out. Afterwards they were referred by DE BLAINVILLE and by GERMAR to the genus *Stromateus,* but it was reserved for AGASSIZ to point out their dissimilarity to all existing forms, and to institute

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[*] *Op. cit.* p. 312.

for them the genus *Platysomus*, which he placed in the "Lepidoid" family of the order Ganoidei.

For an account of the subsequent history of this genus,—its transference to the Pycnodontidæ by Sir PHILIP GREY-EGERTON, to the Stylodontes (Dapediidæ) by Dr ANDREAS WAGNER, and the position assigned to it by Professor YOUNG in his suborder of "Lepidopleuridæ," I may refer to the introduction to this paper.

Species.—Under *Platysomus* AGASSIZ included the species *gibbosus* and *rhombus* from the German Kupferschiefer; *striatus*, *parvus*, and *macrurus* from the English Magnesian Limestone; and *parvulus* and *declivus* from the British coal formation. Professor KING has merged *P. parvus* in *P. striatus*,* and as to the so-called *P. macrurus* (*Eurysomus*, Young), we have already discussed its affinities, and the circumstance that its peculiar dentition, along with the shape of the scales, induced Sir PHILIP GREY-EGERTON with AGASSIZ's approval, to transfer not only it, but the whole genus *Platysomus* to the family of Pynodonts. Neither *P. parvulus* nor *declivus* were described by AGASSIZ, but Professor YOUNG has given a minute description of a fish, which, following Professor WILLIAMSON, he has referred to the former species, and it is chiefly upon its structural features that he has based his account of the cranial osteology of the genus.† *Platysomus declivus* is a MS. name given by AGASSIZ to a specimen from Burntisland, Fifeshire, in the collection of Sir PHILIP GREY-EGERTON, and published by MORRIS in his "Catalogue of British Fossils," p. 339. I am indebted to the kindness of its distinguished owner for an opportunity of examining the specimen, and find that it is in reality a distorted example of *Eurynotus crenatus*, an opinion in which Sir PHILIP also concurs.

By MÜNSTER‡ three species were added, viz.,—*P. Fuldai*, *intermedius*, and *Althausii*, but two of these have been subsequently cancelled. *P. Fuldai* has been merged by GEINITZ§ in *P. macrurus* (*Eurysomus*); and there can be no doubt that Messrs HANCOCK and HOWSE|| were correct in referring *P. Althausii* to *Dorypterus Hoffmanni*, Germar.

From the Coal Measures of Illinois, two species—*P. circularis* and *P. orbicularis*—have been determined by Messrs NEWBERRY and WORTHEN.¶

Messrs HANCOCK and ATTHEY ** have also added two well-marked Carboniferous species to the list, viz.,—*P. Forsteri* and *P. rotundus*, from the Coal Measures of Newsham, near Newcastle, and I myself must now add still another from the Lower Coal Measures of Derbyshire,—

Platysomus tenuistriatus, sp. nov., Traquair (? = *P. striatus*, Young *pars*).

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[*] Catalogue of the Organic Remains of the Permian Rocks of Northumberland and Durham, 1848, p. 15; "Permian Fossils" (Mem. Palæontographical Society, 1850), p. 232.

[†] *Op. cit.* pp. 302–305, woodcut, fig. 2.

[‡] Beiträge zur Petrefactenkunde, v. 1842, pp. 43–47.

[§] Dyas, p. 10.

[||] Qu. Journ. Geol. Soc. xxvi. 1870, p. 627.

[¶] Geol. Survey of Illinois, vol. iv. p. 347, Pl. III. fig. 1; Pl. IV. fig. 2.

[**] Ann. and Mag. Nat. Hist. (4) ix. 1872, p. 252.

Usual length about 3½ inches. Body deep and rounded; back strongly and evenly arched from the occiput to the narrow tail pedicle; ventral contour more gently curved from the throat to the commencement of the anal fin, from which it then slopes rapidly upwards in a manner corresponding to the downward direction of the dorsal line opposite. Flank scales, exclusive of the articular peg, about 2½ times as high as broad; all over the body they are marked externally with exceedingly close and delicate striæ, vertical to the long axis of the fish. Dorsal fin commencing rather behind the highest point of the rounded back, acuminate in front, and falling away to a narrow fringe-like form behind, anal similar in shape, but about one-sixth part shorter. Pectorals small with distinctly articulated rays, ventrals not observable. External bones of head for the most part minutely striated; some granulation observable upon the parietals and frontals; operculum very high and narrow, interoperculum very small.

The above description is principally taken from a specimen in the Museum of Practical Geology, labelled *Platysomus striatus*;* others are in the collections of Messrs E. W. BINNEY, F.R.S. of Manchester, and J. WARD, F.G.S. of Longton. All are from the "Dalemoor Rake" ironstone of Stanton-by-Dale, Derbyshire. Its specific distinctions are clear and unmistakeable. From the large Permian species *gibbosus*, *rhombus*, and *striatus*, it is obviously distinguished by the rounded contour of the back, being especially widely removed from *P. striatus* by the greater anterior acumination of the dorsal and anal fins, and the sharp turning forwards of the dorso-ventral bands of scales so prominent in that species, being here hardly perceptible. From *P. gibbosus* and *rhombus* it is equally distinct. As regards the Carboniferous species, the want of the dorsal peak and the finer sculpture of the scales at once distinguishes it from *P. parvulus*, while from *P. rotundus*, the shorter dorsal fin, the proportionally broader scales, with their closer and more delicate sculpture, are diagnostic marks which strike one at the first glance. *P. Forsteri* is a large species which has not yet been found entire; but the character of the scale ornament is rather different from that of *P. tenuistriatus*, the striæ being more undulating, usually more or less oblique to the anterior margin even in the flank scales, and tending to become abruptly intercalated.

Geological Position.—The genus *Platysomus* is characteristic of the Permian and Carboniferous formations, and if we except the remains catalogued by Messrs YOUNG and ARMSTRONG as "*P. declivus*," from the Carboniferous Limestone of Braehead,† which I have not seen, no trace of it has been found below the

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* This is probably the same specimen from Derbyshire, "in the Jermyn Street collection," to which Professor YOUNG refers (*op. cit.* p. 305), in support of his statement that *P. striatus* is common to the Carboniferous and Permian formations.

† Carboniferous Fossils of the West of Scotland, Glasgow, 1871, p. 75. Catalogue of the Western Scottish Fossils, "British Association Guide Books," Glasgow, 1876, p. 64.

horizon of the Millstone grit. *P. declivus* of AGASSIZ having turned out to be a *Eurynotus,* the genus must at least be struck out of the list of fishes of the Scottish Calciferous Sandstone series, remarkable as these strata for the number and variety of their *Palæoniscidæ.*

Structure.—The body is deep, and the general form usually more or less rhombic, owing to the pointed snout, and the angulation of the dorsal and ventral margins. In *P. tenuistriatus* the back is, however, gibbously rounded; in *P. parvulus* (Pl. VI. fig. 5), it forms a high peak in front of the dorsal fin; more commonly, as in *P. striatus* (Pl. VI. fig. 1), it forms an obtuse angle at the commencement of that fin; the ventral line being more horizontal as far as the commencement of the anal, where, forming an obtuse angle, it slopes rapidly upwards to the tail pedicle.

The scales of the body are arranged in nearly vertical bands, which show, however, a slight backward and downward obliquity, which increases towards the tail; in *P. striatus* these bands, along the origin of the anal fin, turn forwards at an obtuse angle. In shape the scales (figs. 2, 3, 4) are high and narrow on the flank, but as usual they become proportionally lower towards the dorsal, ventral, and caudal aspects. The articular spine is well marked, but the internal rib, close to the anterior margin, as in all the genera of the family save *Eurynotus,* varies in strength in different species, being in some (*P. parvulus, Forsteri*) nearly obsolete. There is a line of small azygous scales, furnished in *P. parvulus* with recurved points, along the dorsal and ventral margins in front of the dorsal and anal fins, and along the upper margin of the caudal body prolongation they are large and V-shaped, while the sides of the same part are clothed with the usual small acutely lozenge-shaped scales, arranged in oblique rows, whose direction is from above downwards and forwards. The external sculpture of the scales is very characteristic of the genus, and consists of fine striæ or ridges more or less vertical to the long axis of the body, consequently tending, on the flank scales, to become parallel with the anterior and posterior margins, numerous specific variations occurring, however, in their relative coarseness or fineness, straightness or wavyness, while in the marginal scales of *P. striatus* some amount of granulation is also observable.

The tail pedicle is slender, the caudal fin deeply cleft and heterocercal, though not very inequilobate, and the prolongation of the body along the upper lobe is comparatively weak. The dorsal fin, commencing at or near the middle of the back, is more or less acuminate in front, and extends fringe-like to the commencement of the tail pedicle; the anal is similar in shape and in relative position on the ventral aspect of the fish, though its base does not extend quite so far forwards. No ventral fins were observed by AGASSIZ, though he introduced them hypothetically into his restored figure of the genus ("Poissons foss." Atlas, vol. ii. Pl. D), and their existence was denied altogether by Professor

Young. Nevertheless, Messrs Hancock and Atthey have expressly recorded the presence of small ventrals in *P. parvulus;* and in a specimen of *P. striatus* in the Edinburgh Museum, traces of a ventral are certainly to be seen; it is, at the same time, at least remarkable that in the immense majority of otherwise well-preserved specimens the fins in question are not observable. The pectorals are frequently well displayed, and are of moderate size. As regards the constitution of the fins, the same type of structure seen in *Eurynotus* and in the Palæoniscidæ is here perpetuated; the rays are closely set, imbricating in the fore part of the fin, divided throughout by transverse articulations, and having their external surfaces ganoid and sculptured. Dichotomisation of the rays commences towards their extremities in the longer rays on the front of each fin, creeping up to the middle in the shorter ones behind. I have not myself been able to detect the presence of fulcra.

In describing the pectoral of *P. striatus,* Agassiz states that its rays "ont cette apparence cornée que l'on observe dans les nageoires de beaucoup de poissons de Solenhofen et qui rend les articulations transversales des rayons imperceptibles." I have, however, very distinctly observed the transverse articulations of the pectoral fin rays in *P. gibbosus, parvulus,* and *tenuistriatus.*

The shoulder girdle (fig. 5) is well developed. The post-temporal element (*p.t.*) is a large plate, somewhat rounded-quadrate in shape, and placed immediately behind the cranial shield and above the operculum; it is usually conspicuous in every specimen of *Platysomus,* and is, no doubt, the part which, in previous descriptions, is usually called "occipital crest." The *supraclavicular* (*s.cl.*) is similar to that of *Mesolepis* and other genera; so is also the *claxicle* (*cl.*), although that is also rather more narrow and elongated. A small, though very distinct *infraclavicular* plate (*i.cl.*) is attached to the front of the lower extremity of the clavicle, but I have not seen any post-clavicular.

In the larger and more typical species of the genus, such as *P. gibbosus* and *striatus,* the bones of the head are seldom clearly decipherable, so that in describing the osteology of this part I must follow the example of Professor Young in using for that purpose the small Carboniferous species *P. parvulus* (fig. 5). Professor Young has given a minute description of the cranial structure of this species, but after a most careful and prolonged examination of a large series of specimens in the collection of Mr Ward, I am unable to make my results agree with his, or to reconcile them with his restored figure of the head.

I can find no trace of the large "supra-occipital" which Professor Young has represented as intercalated, Teleostean-like, between the parietals, and I cannot help strongly suspecting that the bone indicated, along with his parietal, appertains to the large post-temporal plate, which occupies a similar position above the operculum. The real parietals are small plates (*p.*), articulating with each other, as usual, in the middle line, and on the posterior part of the outer margin of each is a small *squamosal* or dermal-pterotic (*sq.*). In front of the parietals are rather short *frontals* (*f.*) arching over the region of the eye, while forming the two posterior-superior margin of the orbit is, on each side, a somewhat triangular-shaped *posterior frontal* or dermal-sphenotic (*p.f.*) placed in front of the squamosal, and external to the anterior part of the outer margin of the parietal, and the posterior part of the outer margin of the frontal. Immediately in advance of the frontals is a narrow elongated median bone (*e.*). Its posterior extremity is somewhat expanded, and presents, behind, an acute angle projecting, wedge-like, into a slight notch between the anterior extremities of the frontals, and on each side an obtuse angle, in front of which the bone tapers gradually to a point, passing down towards the extremity of the snout. This is, without doubt, the median *superethmoidal,* and the homologue of that plate, which in the Palæoniscidæ forms the projection of the snout over the mouth. Placed on each side of this ethmoid, and articulating with the anterior extremity of the corresponding frontal, is another elongated bone (*a.f.*); this is somewhat narrow where its posterior extremity joins the frontal, but suddenly it becomes expanded laterally, so as to form a prominent angle, directed outwards in front of the orbit, from which it again becomes gradually narrowed to a point anteriorly. On its inner margin, near its posterior or upper extremity, is a deep round notch, completed into a foramen (*n.*) by the adjoining superethmoidal, and which foramen is clearly the nasal opening, but placed in a rather different position from that which it was supposed to occupy by Professor YOUNG. This bone (*a.f.*) corresponds in position to the anterior frontal of the Palæoniscidæ, and the nasal openings occupy in reality exactly the same relative position to the orbit as in that family, only the great downward development of the bones of the nasal region, and the consequent "prognathous" character of the face, causes them to assume a position remarkably distant from the extremity of the snout. The close correspondence of the arrangement with that which has been already described in *Mesolepis* is also quite apparent. In front of the last described bones are evident traces of two others, small and narrow, one on each side, which apparently sends back its posterior pointed extremity for a little distance between the adjacent superethmoidal and anterior frontal. Their anterior extremities are never clearly exhibited, nevertheless they seem to pass down to the extremity of the snout, and to be there placed between the anterior extremities of the maxillæ. These may be the premaxillæ, but as yet I have seen no teeth upon them.

A strong parasphenoid bar is seen extending along the base of the cranium, and there are also some traces of ossification in the side walls, but, unfortunately, too indistinct for description.

The *hyomandibular* (*hm.*) is indicated in one specimen as a slender bone extending from above downwards and slightly forwards, with a flattened and somewhat expanded upper extremity, below which it is suddenly constricted, whereupon it once more, though very gradually, increases in diameter towards its lower extremity, which is, however, not well seen. Placed along its posterior margin is the operculum, a high narrow plate, with rounded posterior-superior angle and gently curved posterior margin. Below, it overlaps the interoperculum (*i.op.*) a much smaller plate, whose anterior-inferior angle is somewhat produced so as to pass down close to the posterior extremity of the mandible. In front of these two bones, and covering the hyomandibular extremity, as well as a portion of the cheek, is the *preoperculum* (*p.op.*), a plate of a somewhat triangular form, whose three margins may be designated as posterior, anterior-superior, and anterior-inferior, and its angles as superior, inferior, and anterior. The posterior margin, the longest, is gently convex, and follows the contour of the anterior margins of the two preceding plates with which it is in close apposition; the anterior-superior margin is in contact with the suborbital chain, the anterior-inferior one with the maxilla; the superior and inferior angles are acute, the anterior one very obtuse. On its internal surface (fig. 8) a fine ridge is seen connecting its superior and inferior angles, which corresponds with a slime canal traversing its interior on its way to the mandible.

In none of the numerous specimens which I have examined is the palato-quadrate apparatus exhibited, a fact which may be accounted for by the heads being almost always crushed quite flat, and the parts in question covered up by the large external facial plates.

The maxilla (*mx.*) is of a broad triangular shape. Its inferior margin is gently convex, so is likewise the posterior one, which is in contact with the preoperculum; the superior margin slopes downwards and forwards to the anterior extremity. Its external surface is sculptured with fine vertical striæ, save on a small area distinctly marked off along the superior margin, deepening towards the extremity of the bone and overlapped by the large anterior suborbital. The mandible is weak, slender, tapering, and gently curved with upwardly directed concavity; its constituent elements, with the exception of the dentary, are not recognisable. From below the interoperculum a set of narrow branchiostegal plates extends on each side between the ravine of the mandible; their exact number cannot be determined, though I have counted at least six.

The orbit (*or.*) is placed high up and far back on the head, its position being right above the articulation of the mandible. There is evidence that it is surrounded in the first place by a complete ring of very narrow osseous plates, besides which there are, as in the other members of the family, two outer suborbital plates (*s.o.*). One of the latter set, narrow and somewhat curved, lies along the posterior-inferior aspect of the orbit, being also in contact with the anterior-superior margin of the preoperculum, the other of an oblong shape joins it in front, and is then placed along the upper sloping margin of the maxilla, which it overlaps, while internally it is in contact with the outer margin of the anterior frontal in front of the orbit.

So far as they can be deciphered, the heads of the other species of the genus seem to agree in their osteology in all essential points with that of *P. parvulus*, as described above.

The dentition of the true *Platysomi* is quite unlike that of *Eurysomus*, Young, or of *Globulodus*, Münster. We have already seen that Agassiz states that the jaws of Platysomus were armed with "petites dents en brosse très-pointues," and that in *P. gibbosus* "ou aperçoit quelques petites dents au bord du maxillaire," although he afterwards suspected the identity of *Globulodus* with the present genus. Professor Young states that the jaws of *P. parvulus* are "armed with slender conical teeth, those in the lower slightly larger and more distant than those in the upper jaw." Messrs Hancock and Atthey describe the dentition of *P. rotundus* in the following terms:—"The mandibular teeth are minute, conical, and pointed; those of the maxillaries are of the same character, but more minute; on the premaxillaries they seem a little larger." And regarding *P. Forsteri* the same authors proceed to state—"The mandibular teeth are large, conical, stout, and obtusely pointed; those of the maxillæ are small, conical, and tubercle-like, with wide bases and recurved apices, and are disposed without order along the alveolar border."

So far as my own observations go, I have only seen the teeth clearly as they exist in the maxillary bones of *P. Forsteri* and *P. parvulus*. As regards the former species, I can certainly corroborate the description given by Messrs Hancock and Atthey. There the maxillary teeth resemble small tubercles, and are irregularly arranged in a narrow band, which passes along the inner aspect of the bone just above the lower margin. In *Pl. parvulus* (Pl. VI. fig. 11) the appearances are somewhat different; the teeth being arranged in one row on the lower margin of the maxilla. They are nearly equal in size and excessively minute, requiring a strong lens for their examination; in shape they are cylindrical, becoming slightly enlarged towards the apex, when they become suddenly and rather obtusely pointed. The expression "slender conical" used by Professor Young in reference to the teeth of this species, would I think tend to recall the form of tooth prevalent in the Palæoniscidæ, whereas in reality they more resemble those of *Æchmodus*; there is also no very material difference between these maxillary teeth of *P. parvulus* and the mandibular ones of *Mesolepis*.

Very little has been said as to the endoskeleton of the trunk in the genera of Platysomidæ already examined, the internal bones being always more or less obscured and hidden from view by the thick outer covering of scales. Such strong glimpses, however, as we do occasionally obtain lead us to suppose that the arrangements did not materially differ from those in *Platysomus*. In this genus the same difficulties are also encountered, but to a less degree, as in many specimens from the Magnesian Limestone and Kupferschiefer, the bones are to a considerable extent perceptible through the scales, or are here and there actually exposed by the removal of patches of scales with the counterpart.

AGASSIZ has given a restored figure of the skeleton of *Platysomus*, which may serve as a basis for the following few remarks on the subject. It is hardly necessary to begin by pointing out that the osteology of the head and shoulder as here delineated is quite erroneous, but for that ample allowance must be made, considering the specimens at his disposal, and the enormous amount of work he executed in so short a time. More attention must be paid to the parts behind. Here the vertebral axis is represented as segmented into distinct centra by vertical dotted lines; above, it gives off a series of short neural arches and spines directed obliquely upwards and backwards; below, a corresponding set of hæmal ones; while in the abdominal region short ribs are delineated, extending hardly more than $\frac{1}{4}$ of the depth of the abdominal parietes. Above the neural spines, and extending from the occiput to the tail, is a lower or proximal set of interspinous bones (*interapophysaires*), the most anterior of which are consequently placed far in advance of the dorsal fin, and they are also inclined downwards and backwards so as to be placed at right angles to the neural spines beneath; they gradually, however, alter their direction, so as posteriorly to become more in a direct line with the spines. The dorsal fin itself is represented as borne by a second or distal set of short interspinous bones (*surapophysaires*) limited in extent to the length of the fin, whose rays, enlarged at their proximal extremities, are articulated to the extremities of these supporting ossicles, with which they also correspond in number. The anal fin is also represented as supported by two sets of interspinous bones, the proximal set commencing with one very large one immediately behind the abdominal cavity.

Now, in the first place, there can be little doubt that the vertebral axis of *Platysomus* was not provided with ossified centra, but consisted of a persistent notochord. It is so described by HECKEL, who refers its condition in this genus to the same category as that in *Palæoniscus* and *Cœlacanthus*, of which he states that they possess in the vertebral axis "durchaus keine Spur von Wirbeln, oder auch nur von Halbwirbeln. Hier sind blosse Dornfortsätze vorhanden, die mit einer Art von Gabeln, welche theils die Stelle der Wirbelbögen, theils von vereinigten untern Querfortsätzen vertreten, über und unter einer nackten Rückensaite ansitzen."* Nor have I myself ever seen any trace of

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* "Ueber die Wirbelsäule fossiler Ganoiden," Sitzungsb. der Wiener Acad. 1850, Abth. 2, p. 363.

vertebral bodies either in this or in any other genus of the family to which it belongs. It is also incorrect to represent the rays of the dorsal and anal fins as equal in number to their supporting interspinous bones and articulated to their extremities; the real state of matters being, that as in the Palæoniscidæ their rays are more numerous than the ossicles which carry them, whose extremities they also overlap.

On the other hand it is abundantly and clearly demonstrable that AGASSIZ was perfectly correct in representing the dorsal and anal fins as borne by two sets of interspinous bones, of which the proximal set (*interapophysaires*) extends right on to the occiput; while the distal set, immediately supporting the rays, is limited in extent to the length of the fin. I should think it also extremely probable that two sets of interspinous bones were also present in the case of the anal fin, though in the specimens I have examined the evidence is not quite so clear, but I am inclined to doubt the existence of the specially large one which in AGASSIZ's figure commences the series immediately behind the abdominal space. Regarding the presence or absence of ribs I regret that I am unable to offer any original observations.

CONCLUSION.

From the researches recorded in the preceding pages, it will now be abundantly clear that the genera treated of forms a connected series whose leading structural features may be summed up as follows:—

The body, deeply fusiform in *Eurynotus*, or ovoid as in *Benedenius*, becomes very deep and laterally flattened in most of the genera, and often rhombic in its contour. The tail is completely heterocercal and accipenseroid in aspect; the deeply cleft caudal fin is strongly inequilobate in some, less so in others; the dorsal margin of the caudal body prolongation is set with a line of imbricating V scales, its sides clothed with small scales of an acutely lozenge-shaped figure. The scales of the body are arranged in dorso-ventral bands, which in the more deeply bodied forms become less oblique and more vertical in their direction. The scales are articulated by strong pointed processes of the upper margin, and in all save *Eurynotus* (Benedenius ?) the vertical rib or keel of the attached surface is coincident with or close to the anterior margin. The dorsal fin is long, and, commencing at or behind the middle of the back extends to the tail pedicle, while the anal shows every gradation from the short-based triangular shape seen in *Eurynotus* and *Benedenius* to one closely simulating the dorsal in form and extent (*Platysomus*). The paired fins are largely developed in *Eurynotus*, but they seem to become relatively smaller as the body deepens; this is especially the case with the ventrals, which are rarely seen in Platysomus, and have not yet been detected in *Cheirodus*. The fins are provided with fulcra (certainly distichous in *Eurynotus*), their rays are ganoid externally, closely set, articulated throughout, and in the fore part of the fin their demi-rays imbricate from before backwards.

The line of the top of the head slopes downwards and forwards at an angle, which in some forms (*Platysomus*) becomes very high, and usually shows a slight convexity or rounded angle above and in front of the orbit. The snout is pointed and prognathous, and the orbit and nasal openings tend to become more and more removed from it in an upward and backward direction. The cranial roof is covered with ganoid plates corresponding to those of the Palæoniscidæ. There are two parietals touching each other in the middle line, each of which is flanked by a squamosal (dermal-pterotic). Over the orbits are two frontals, and on each side a posterior frontal (dermal-sphenotic) forming the posterior-superior orbital margin, and an anterior frontal (lateral dermal-ethmoidal) forming its anterior-superior boundary. Between the anterior frontals is a medium superethmoidal, and the nasal openings are formed each by a rounded notch on the outer side of the superethmoidal, completed by a similar one on the opposed margin of the adjacent anterior frontal. The hyomandibular slopes downwards and usually also a little forwards; the osseous part of the palato-quadrate apparatus displays, in *Cheirodus* at least, three bony elements, pterygoid, mesopterygoid and quadrate, of which the pterygoid is by far the largest. The mandible shows the presence of articular, dentary, angular, and splenial pieces, its external aspect being occupied almost entirely by the dentary. The maxilla is a more or less triangular plate, the præmaxilla is pointed and often beak-like.

The opercular apparatus consists of an opercular plate, below which is an interopercular, often as large as, or even larger than the opercular, while the preoperculum placed in front of these covers the hyomandibular as well as also a portion of the cheek. The branchiostegal rays take the form of narrow imbricating plates, and where, as in *Eurynotus* and *Cheirodus*, a favourable view has been obtained, a median lozenge-shaped plate is seen connecting the right and left series behind the symphysis of the mandible. The orbit is bounded below and behind by a chain of suborbital plates, besides which there is evidence of a narrow circumorbital ring passing round its entire circumference.

The teeth vary very much in shape in different genera, but so far as yet observed never display the acutely conical form characteristic of the Palæoniscidæ. They may be either tubercular or obtuse, with or without constricted neck or base, or cylindro-conical, with constricted base more or less marked. They are usually present upon the splenial and on the pterygoid, not always so upon the dentary of the mandible, the maxillary margin, or upon the præmaxilla.

The notochord is persistent, but the neural and hæmal arches and spines are ossified. The neural spines are succeeded above by a proximal set of interspinous bones, which in *Platysomus* at least extend forwards as far as the occiput, above which is a second or distal set supporting the rays of the dorsal fin. The arrangements on the hæmal aspect are probably essentially similar as regards the presence of two sets of interspinous bones. The rays of the median fins exceed their supporting ossicles in number, and also overlap their extremities.

This series of forms may, I think, in the present state of science, be taken as forming a family, for which the name *Platysomidæ* will be appropriate, as the genus *Platysomus* was not only the first known of the group, but in its structure the peculiarities characteristic of the series seem to have attained their greatest amount of specialisation. Further subdivision of the family may at present remain unattempted, for although distinct "subfamilies" seem certainly to be represented by the genera *Eurynotus, Mesolepis, Cheirodus,* and *Platysomus,* yet there is considerable difficulty in dealing with *Benedenius* and *Wardichthys,* inasmuch as their entire structure is not yet sufficiently known.

Affinities of the Platysomidæ.

It now remains for us to endeavour to ascertain the position of the Platysomidæ in the system, or, in other words, to inquire as to the relative amount of structural affinity which they betray to other groups of fishes, fossil or recent.

Opinions of Previous Authors.—We have seen in the introduction to this memoir, that various opinions as to the position and classification of the genera here ranked as Platysomidæ have been maintained by various authors, which opinions may now be briefly recapitulated.

1. Agassiz originally classed *Eurynotus* and *Platysomus,* along with *Palæoniscus* and *Amblypterus,* in the Heterocercal division of his family Lepidoidei belonging to the order Ganoidei.

2. Giebel classed the above-named forms, along with others, in his group of Heterocerci Monopterygii.

3. Grey-Egerton placed *Platysomus* in the family Pycnodontidæ, in which he also included *Tetragonolepis,* at the same time leaving *Eurynotus* with *Palæoniscus* in the Agassizian group of Lepidoidei Heterocerci.

4. Vogt classified *Eurynotus* and *Platysomus* along with *Palæoniscus* in the subfamily Palæoniscidæ of his family Monosticha, in which a second subfamily was constituted by the Dapediidæ.

5. Wagner placed *Platysomus* in his family "Stylodontes," in which it was associated with *Tetragonolepis* and *Dapedius.*

6. Young divided the genera, which in this essay are taken together as Platysomidæ, into four distinct families of *Platysomidæ, Amphicentridæ, Eury-*

somidæ, and *Mesolepidæ*. These he associated with the Pycnodontidæ in one "suborder" which he named "Lepidopleuridæ," and from which he excluded *Tetragonolepis* and *Dapedius*.

7. Lütken accepted the "Lepidopleuridæ," but divided the series into the three groups of Platysomi, Pleurolepidæ, and Pycnodontidæ, including in the first of these the fishes distributed by Professor Young in his four families of Platysomidæ, Amphicentridæ, Eurysomidæ, and Mesolepidæ. While admitting that the affinity between the Platysomi and Palæonisci is incontestable, he maintained that the former were inseparably allied to the Pycnodonts.

8. Victor Carus followed Lütken in reuniting the Platysomid fishes into one family, and in retaining the suborder Lepidopleuridæ, in which, besides the Platysomidæ, he also included the families of Pycnodontidæ and Pleurolepidæ, the latter to contain *Tetragonolepis*, but not *Dapedius*.

9. I have myself maintained that the Platysomidæ are more nearly related to the Palæoniscidæ than to any other group, and have included both families in one suborder with the Chondrosteidæ, Polyodontidæ, and Acipenseridæ. For this suborder I have considered the term "Acipenseroidei" more suitable than the Müllerian "Chondrostei."

10. Professor Cope has included *Eurynotus* along with *Palæoniscus*, *Lepidotus*, *Pholidophorus*, &c., in the family Lepidotidæ, while he has placed *Platysomus* along with *Tetragonolepis* and *Dapedius* in the Dapediidæ, and retained the Pycnodonts as a family by themselves. All these three families are included in his order of Isospondyli.

The whole question then resolves itself into the following:—In what sort of relationship do the Platysomid fishes stand to each of the three families of Dapediidæ, Pycnodontidæ, and Palæoniscidæ?

Relationship to the Dapediidæ.

In approaching this question special notice must first be taken of the genus *Tetragonolepis* of Bronn (Agassiz *partim*), the peculiar form of whose scales has frequently led to its association with the Platysomidæ, or with the Pycnodontidæ. It is certainly impossible to regard *Tetragonolepis* as a member of the Pycnodont family, nor can it in any classification be disassociated from *Dapedius*. On this point Wagner and Cope are undoubtedly right, for the mere fact that the scales of *Tetragonolepis* have their internal rib or keel placed along the anterior margin, cannot outweigh the manifest resemblance which it betrays to *Dapedius* in the osteology of the head, in the internal skeleton, and in the form of the body and fins. To see that *Tetragonolepis* has a Dapedioid and not a Pycnodont head, one need only look at the beautiful figure of *T. discus* given by Sir Philip Grey-Egerton himself in his paper on the genus; and as regards the dentition, Dr WAGNER, after noticing the absence of the characteristic Pycnodont "Vorkiefer" or premandibular bone, states that the teeth have the same configuration as in *Æchmodus.*[*]

If therefore *Tetragonolepis* belongs, not to the Pycnodontidæ, but to the Dapediidæ (*Stylodontes,* Wagner), it is to my mind also a step in the wrong direction to include *Platysomus* with it in the same family.

For the Dapediidæ (including *Tetragonolepis*) differ most materially from *Platysomus* and its allies in having a few-rayed semiheterocercal Lepidosteoid caudal fin, instead of the many-rayed heterocercal and Acipenseroid one of *Platysomus;* in the manner in which the rays of the dorsal and anal fins correspond in number to their supporting interspinous bones; in the presence of long ribs, and of well-ossified hemivertebræ (though the notochord is also persistent); and in the absence of infraclavicular plates. With these obvious differences in the structure of the body is associated, as might be expected, an equally striking dissimilarity in the osteology of the head, as may be seen by referring to the restored figure of the head of Dapedius which I have constructed (Pl. VI. fig. 13), after careful study of the large series of specimens in the collections of Lord ENNISKILLEN, of the British Museum, and of the Museum of Practical Geology.[†] Without entering into any detailed description, it may be sufficient to point out that the general features here exhibited are not those of the Platysomidæ, but those of the more modern type of Ganoids exemplified in the fossil *Lepidotus, Semionotus,* &c., and in the recent *Lepidosteus* and *Amia;* in particular, we may note the completely Teleosteoid aspect of the opercular apparatus in which the preoperculum does not extend forwards on the cheek, and has associated with it an operculum, suboperculum, and interoperculum, arranged quite according to the ordinary pattern. The styliform shape of the teeth in some Platysomidæ, and the deep form of the body in the Dapediidæ, with the shape of the scales in the special genus *Tetragonolepis,* seem to me to be characters of small importance when placed against the differences in general structure, which certainly forbid their association in one "family," according to

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[*] "Münchener Gelehrte Anzeigen," 1860. Dr WAGNER here uses QUENSTEDT'S name *Pleurolepis* for *Tetragonolepis* of Bronn, and *Tetragonolepis* for *Æchmodus* of Egerton. *Æchmodus* is distinguished from *Dapedius,* De la Beche, only in having the apices of the teeth simple instead of bifid; but as Sir PHILIP GREY-EGERTON has himself pointed out, both forms of tooth may occur in the same specimen, and the name *Æchmodus* is therefore not maintainable. As to the use of "*Pleurolepis,*" its priority over *Tetragonolepis* cannot be maintained. It is true that QUENSTEDT first pointed out that *Tetragonolepis semicinctus,* Bronn, was generically distinct from the other species added by AGASSIZ to the same genus, but surely, instead of inventing a new name for the first, and passing *Tetragonolepis* on to the others, he ought to have preserved the original generic name for the original type.

[†] The restored figure of the head of "*Æchmodus,*" given by Professor YOUNG in his paper "On the Affinities of *Platysomus,*" is incorrect in at least one important particular, namely, in representing the parietals as pushed outwards to a position behind the squamosals by an intruding compound "supraoccipital." The plate, which he has lettered as "post-frontal," seems to me to be only a member of the circumorbital ring.

the usual conceptions of the limits of such a zoological division. To my mind, those differences express a separation of still wider extent than one of mere "family" importance.

Relationship of the Platysomidæ to the Pycnodontidæ.

The Pycnodonts form a remarkable and most distinctly characterised family of extinct fishes, which range from the Liassic to the Eocene rocks inclusive, and whose zoological position is even yet rather problematic in its nature. And the Platysomidæ seem to be still less related to them than even to the Dapediidæ.

The Pycnodonts may be said to resemble the Platysomidæ in the following few points:—

1. The shape of the body is deep; the dorsal fin extends from near the middle of the back to the tail pedicle, and the anal agrees with that of *Platysomus* at least, in being nearly the counterpart of the dorsal in form and position. The contour of the top of the head slopes steeply downwards and forwards, and usually shows a slight convexity in front of the orbit, which is placed rather high up and far back; the snout is pointed and "prognathic" in aspect.

2. The scales, sometimes limited to the anterior part of the body, are mostly high and narrow, and have their internal rib or keel coincident with the anterior margin, and passing up into a strong spine, which articulates with the bevelled-off lower extremity of the rib of the scale next above.

3. The notochord is persistent.

The differences, on the other hand, are of a very much more important character—

1. The osteology of the head of the Pycnodontidæ is not yet in every particular satisfactorily elucidated; certain facts are, however, well established, which are completely at variance with anything observable in the Platysomidæ. The most salient feature in the Pycnodont head is the altogether peculiar construction of the masticatory apparatus. The maxilla is a thin edentulous lamina, which is rarely seen. The long premaxillary bones carry a few styliform or chisel-shaped "incisor" teeth, behind which the roof of the mouth is occupied by a long median bone, supposed to be the vomer, or united parasphenoid and vomer. The straight sides of this bone slightly converge anteriorly, so that it is narrower in front than behind, it is gently convex longitudinally, and bears several rows of rounded or oval flattened crushing teeth, there being usually five of these rows, one median and two lateral. This bone, with its formidable armature, bites below into a longitudinal hollow formed by the apposed right and left rami of the very stout mandible, each ramus being provided also with several rows of flattened teeth, usually four, and at its symphyseal extremity,

also with a peculiar accessory premandibular piece, the "Vorkiefer" of the Germans, which carries a few "incisors" like the opposed premaxilla. It need hardly be said that nothing at all like this remarkable arrangement occurs in any one of the Platysomidæ, not even in *Cheirodus,* in which the margin at least of the maxilla is edentulous, but whose palatal teeth are borne upon the moveable pterygoid bones like those of *Eurynotus.*

In many other respects the head in the Pycnodonts differs remarkably from that in the Platysomidæ. For instance, the greater part of the cheek is covered by a mosaic of small polygonal plates, as is also the throat between the mandible and the lower extremities of the clavicles. Different opinions have been expressed as to the number of opercular pieces; like QUENSTEDT, I have myself been only able to distinguish one, the operculum, below which are only two narrow branchiostegal rays instead of the long series, which in the Platysomidæ extends forwards below the mandible; and from this, as well as the appearance of the throat, it seems pretty clear that the external branchial cleft or opening was limited below, as in the modern Plectognathi, and did not form the long slit seen both in the Platysomidæ and Palæoniscidæ.

2. The clavicle differs in shape at its lower extremity from that of the Platysomidæ, and the infraclavicular plates are altogether absent.

3. The vertebral axis is notochordal, but the neural and hæmal spines spring from well-developed hemivertebræ, which in *Pycnodus* join each other by suture above and below on the sides of the chorda. The neural and hæmal arches are connected with each other by horizontal denticulated articular processes, and the spinous processes are very long, the neural ones in front of the dorsal fin reaching nearly to the margin of the body. The abdominal region is provided with long and well-developed ribs.

4. The dorsal and anal fins are supported each by only one set of interspinous bones, and these have their proximal extremities inserted between the extremities of the neural and hæmal spines, as in modern fishes.

5. Fulcra are entirely absent from all the fins, and the rays of the dorsal and anal correspond in number to their supporting interspinous bones, to whose extremities they are articulated.

6. The caudal fin is only semiheterocercal, and in those genera in which the entire body is covered with scales (*Gyrodus, Mesturus*), the heterocercy is almost completely masked, when the scales are well preserved in the caudal region.

Many genera, mostly founded upon fragmentary remains, have been added to the Pycnodontidæ, chiefly or only on account of the possession of flattened teeth, and in some of these instances, *e.g.*, the reptilian *Placodus,* the reference to this family has been subsequently found to be rather wide of the mark. But, looking at these forms whose claim to be considered as Pycnodonts is established by a knowledge of the entire fish, no more compact or sharply defined group can be found in the whole range of ichthyology. In spite of the persistence of the notochord, the whole structure of these fishes evinces a high degree of specialisation, and the absence of connecting links with more generalised forms renders the systematic position of the family indeed hard to determine, though the structure of the internal skeleton seems to indicate that it appertains rather to the great Lepidosteoid series of Ganoids than to any other. One thing is certain, namely, that the Pycnodontidæ are widely separated from the Platysomidæ by an assemblance of characters, upon which the anatomist is compelled to place very much greater weight than upon the mere external form of the scales.*

The Suborder "Lepidopleuridæ" of Professor YOUNG.

We have already seen in the introduction to this paper that Professor YOUNG, unable to include the Platysomidæ and Pycnodonts in one "family," proposed, apparently as a sort of compromise, to institute the "suborder" of *Lepidopleuridæ*, in which both should be comprised, and which should be equivalent to the suborders Amiadæ, Lepidosteidæ, Crossopterygidæ, Lepidosteidæ, and Acanthodidæ, in Professor HUXLEY's system. We may now briefly analyse Professor YOUNG's definition of the "Lepidopleuridæ," with the view of coming to some conclusion as to its validity as a suborder of Ganoids.

He states that the Lepidopleuridæ are,—

"Ganoids with heterocercal equilobate tails. Body rhomboidal, covered with rhombic scales articulated by strong ribs traversing their anterior margin internally. Dorsal fin equal to half the length of the trunk. Anal fin also with an elongate base. Ventrals when present small. Paired fins non-lobate. Branchiostegal rays not taking the forms of broad plates. Notochord persistent. Arches well ossified."

Some of these characters are obviously inapplicable to many prominent members of the assemblage of fishes which Professor YOUNG here proposes to

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* Besides AGASSIZ's "Poissons Fossiles," the following works may be consulted in connection with the structure of the Pycnodontidæ :—

GREY-EGERTON, Sir PHILIP. "On the Affinities of Platysomus." Qu. J. Geol. Soc. v. 1849.

WAGNER, Dr A. "Beiträge zur Kenntniss der in den lithographischen Schiefern Bayerns abgelagerten urweltlichen Fische." Abh. Bayer. Ac. vi. 1850.

WAGNER, Dr A. "Monographie der fossilen Fische aus den lithographischen Schiefern Bayerns," pt. i. Abh. Bayer. Ac. ix. 1861.

THIOLLIÈRE, VICTOR. "Poissons Fossiles du Bugey," pt. i. Paris, 1854.

HECKEL, J. J. "Beiträge zur Kenntniss der fossilen Fische Oesterreichs." Denkschr. Wien. Ac. xi. 1856.

QUENSTEDT, F. A. "Handbuch der Petrefactenkunde," second ed. Tübingen, 1867.

bring together. The Pycnodonts are not heterocercal in the same sense as *Platysomus, Eurynotus,* &c., but are nearly as homocercal as the Salmonidæ; nor is the tail of *Eurynotus,* or of *Mesolepis* "equilobate." The anal fin of *Eurynotus* has not an elongate, but a short base, and the ventral fins, both in it and in *Mesolepis,* are of very respectable size.

Other characters, whatever value they may have in distinguishing families and genera, are hardly admissible in the definition of a "suborder" of fishes, being merely part of the endless variations and coincidences in external form which the process of specialisation brings out in forms which may either be very distantly related or closely allied. Such are the deep shape of the body (which here cannot be called "rhomboidal" in every case), the length of the dorsal and anal fins, and the small size of the ventrals, even if these peculiarities of the two last named fins held good with all the genera, which is not the case. Similarly, I cannot look upon the form of the scales as being a character of prime importance, though it certainly is of greater value than the depth of the body, or the length or size of a fin.

For, if we compare the scales of *Palæoniscus* (Pl. VI. fig. 16), or of *Eurynotus* (Pl. III. fig. 3), with those of *Platysomus* (Pl. VI. figs. 3, 4) and of *Gyrodus* (Pl. VI. figs. 14, 15), it becomes perfectly clear that the so-called "scale rib" or "Lepidopleuron" of the last-named genera is no special or isolated phenomenon, but is, after all, nothing more or less than that vertical keel which is characteristic of the under surface of the scales in almost all rhombiferous Ganoids, and which ordinarily passes up into or ends a little in front of the base of the articular spine, besides being bevelled off inferiorly by the anterior margin of the little fossette which lodges the spine of the scale next below. This keel may be in some cases prominent, in others obsolete, in some more or less central, in others placed at or near the anterior margin. Of course in the true Pycnodonts these "scale ribs" form very prominent objects from the thinness, and in some cases the entire absence of the rest of the scale. But for my own part, I cannot understand how the mere marginal position of such a keel can ever carry with it so great a morphological importance as to entitle it to be used as a SUBORDINAL character, especially when contradicted by obvious facts of structure, cranial, or otherwise. But it is indeed hardly necessary, at the present day, when AGASSIZ's system of classification of fishes, according to their scales, is a thing of the past, to dwell upon the fact that all attempts to found any large groups upon the mere external configuration of these appendages must prove utterly futile.

Again, the non-lobate nature of the paired fins, and the branchiostegal rays not taking the form of broad (jugular) plates, are characters shared also by the Amioid and Lepidosteoid Ganoids, and in many of the latter the notochord is also persistent, with well-ossified arches. It is here not meant that no characters can be used in the definition of a group except such as are altogether absent from every other with which it is compared. For example, it is perfectly legitimate in comparing the Acipenseroid and Lepidosteoid Ganoids to bring forward the presence of infraclavicular plates in the former and their absence in the latter, although these plates are also present in Crossopterygii, because the latter are in their turn separated from the Acipenseroidei by other important characters, such as the presence of jugular plates and the lobation of paired fins. What we require is that the *assemblage of characters* shall be exclusive. And it certainly seems to me that the characters assigned by Professor YOUNG to his Lepidopleuridæ are, both taken individually, and in the aggregate, quite insufficient either to characterise a sub-order, or to differentiate the fishes therein included from the Lepidosteidæ of Professor HUXLEY; while, on the other hand, the wide gulf which exists between the Platysomidæ and Pycnodontidæ, in certain very essential points of structure, is ignored.

The suborder Lepidopleuridæ must, therefore, in my opinion, be abandoned, and the affinities of the Platysomidæ traced in another direction.

Affinities of the Platysomidæ with the Palæoniscidæ.

The Platysomidæ agree with the Palæoniscidæ in the following points:—

1. The vertebral axis is notochordal; the neural and hæmal spines are short; and there are two sets of interspinous bones, proximal and distal, supporting the rays of the dorsal and probably also of the anal fin.

2. The fins are fulcrated.

3. The rays of the median fins are more numerous than their supporting interspinous bones, which they overlap with their proximal extremities; they are closely set, closely jointed, and in the anterior part of each fin the demi-rays are closely imbricated.

4. The caudal fin is completely heterocercal and acipenseroid in aspect, and the upper margin of the body-prolongation is set with a row of pointed imbricating V-scales.

5. The paired fins are similar in structure in both families, though the ventrals are small in some Platysomidæ, and not observed in others. The shoulder girdle is composed of the same elements, which in both families have an exceedingly similar shape, and include well-marked infraclavicular plates.

6. The osteology of the head is morphologically similar in both. The cranial roof bones correspond, plate for plate, both in number and in their relative positions to each other, and the nasal opening on each side is situated between the median superethmoidal and the dermal anterior frontal. As in the Palæoniscidæ, the preoperculum extends forwards on the cheek, and the other oper-

cular bones, as well as the branchiostegal rays, are extremely alike. The hyomandibular is a rod-like bone, without evidence of appended symplectic; the bony palate consists of three elements—pterygoid, mesopterygoid (?), and quadrate—similarly related to each other as in the Palæoniscidæ, and the mandible is also identical in its construction.

7. The scales of *Eurynotus* are quite conformable in shape to the type characteristic of the Palæoniscidæ, and the dissimilarity observed in the other genera of Platysomidæ is not of so essential a character as has been supposed.

On the other hand, the differences between the two groups, though striking enough, are quite insufficient to conceal the close affinity between them.

1. In the Platysomidæ the body tends to become deep and short, and to assume an ovoid, circular, or rhombic contour.

2. Though still conformable in essential morphological features to the Palæoniscoid type, the cranial osteology in the Platysomidæ has undergone a remarkable modification characteristic of the family.

In *Palæoniscus*, as in the recent *Polyodon*, the direction of the axis of the base of the skull continues forwards that of the vertebral column in pretty nearly a straight line. The premaxillæ are very small, the anterior frontal and the median superethmoidal short, and the latter forms a prominence over the front of the mouth. The mouth, with its enormously wide gape, is itself, as it were, drawn backwards by the great posterior obliquity of the hyomandibular, and, coincident with this, the orbit assumes a remarkably anterior position close to the snout, and also close above the front part of the mouth, the upper margin of the maxilla being consequently suddenly excavated or cut away to make room for it.

In the Platysomidæ, on the other hand, along with the deepening of the body, the line of the base of the skull, assuming a downward and forward slope, forms an angle with that of the vertebral axis, the contour of the top of the head becoming also more or less steep and inclined. Altering its backward obliquity, the hyomandibular has now become, as it were, in pendulum fashion, swung forwards, so as to assume either a vertical or a slightly forward as well as downward direction, while the bones of the ethmoidal region become elongated downwards and forwards. The mouth is thus carried downwards and forwards, and becomes less wide than in the Palæoniscidæ, and more or less "prognathous," while the nostrils and orbits, remaining behind, appear remarkably high up in relation to the mouth and snout, while all that remains of the ethmoidal prominence of the Palæoniscidæ is a slight convexity in the contour of the head in front of the orbits. The maxilla consequently no longer requires to have the front part of its upper margin cut away to accommodate the eye, and appears as a simple triangular plate, and a large anterior suborbital or "lachrymal" becomes developed to fill up the space between it and the anterior frontal.

This type of skull, which reaches its most extreme development in *Platysomus,* is strongly marked even in *Eurynotus,* but not so much so in *Benedenius,* although the Platysomid nature of the last mentioned genus is sufficiently indicated by the backward position of the orbit and the vertical direction of the hyomandibular bone.

3. While the Palæoniscidæ, with very few exceptions (*Gonatodus, Microconodus*), possess acutely conical teeth of different sizes, that form of tooth is in the Platysomidæ either absent or very rarely seen. But the remarkable differences in the external shape of the teeth displayed by the various genera of Platysomidæ themselves amply show that the shape of the teeth is here of very little systematic value.

4. In the majority of Platysomidæ the scales of the body have the keel of the internal surface, which passes above into the articular spine, coincident with, or close to the anterior margin. This is, however, not the case in *Eurynotus.*

5. The dorsal fin has an elongated base, and the anal fin tends to assume a similar form, though it is short-based in *Benedenius* and *Eurynotus.*

6. The ventral fins are in some Platysomidæ very small (*Platysomus*), or possibly absent, as in *Cheirodus.*

Weighing these points of resemblance and difference together, it is quite obvious that the latter are of a much more superficial nature than the former; in other words, the Platysomid type is simply a modification of the Palæoniscoid one. The Platysomidæ are *specialised Palæoniscidæ.*

Stray glimpses of the progress of this specialisation are also, in fact, exhibited to us in contemplating the series of Platysomid genera. *Benedenius,* though in my opinion standing upon the Platysomid side of the boundary, is considerably more Palæoniscoid in aspect than the rest of the family. The head of *Eurynotus* is decidedly, indeed strongly, Platysomid in structure, but from the body it would, in spite of its long dorsal fin, be hard to refuse it a place in the Palæoniscidæ. The anal fin in *Benedenius* and *Eurynotus* is short-based, like that of *Elonichthys;* that of *Mesolepis* has already considerably extended in length, while in *Cheirodus* and *Platysomus* the anal has become nearly as long as the dorsal.

The genera of Platysomidæ do not, however, form a straight line. *Cheirodus* branches off in a rather different direction from *Platysomus,* and it is abundantly evident that, although the relationship of the Platysomid genera to each other and to the Palæoniscidæ favours the doctrine of Evolution, many genera have yet to be discovered before the line of descent can be satisfactorily exhibited.

Final Summary.

We are now, I think, justified in concluding,—

1. That the Platysomidæ are specialised forms, which have, if the doctrine of descent be true, been derived from the Palæoniscidæ. Their structure presents us simply with a modification of the Palæoniscoid type, and wherever the Palæoniscidæ are placed in the system, thither the Platysomidæ must follow.*

2. The resemblances between the Platysomidæ and the Dapediidæ and Pycnodontidæ are mere resemblances of analogy, and not of real affinity. The Dapediidæ are related not to the Palæoniscidæ or Platysomidæ, but to the other semiheterocercal Ganoids of the Jurassic era (*Lepidotus*, &c.), and the Pycnodonts are highly specialised forms, whose general affinities point in the same direction.

EXPLANATION OF THE PLATES.

Throughout these figures the same letters apply to the same bones.

p.	Parietal.
sq.	Squamosal or dermal-pterotic.
f.	Frontal.
p.f.	Posterior frontal or dermal-sphenotic.
a.f.	Anterior frontal or dermal-ectoethmoidal.
e.	Median superethmoidal.
p.mx.	Premaxilla.
mx.	Maxilla.
pt.	Pterygoid.
m.pt.	Mesopterygoid.
h.m.	Hyomandibular.
ar.	Articular.
a.g.	Angular.
d.	Dentary.
sp.	Splenial.
op.	Operculum.
i.op.	Interoperculum.
p.op.	Preoperculum.
br.	Branchiostegal.
s.o.	Suborbital.
s.t.	Supratemporal
n.	Nasal opening.
or.	Orbit.
p.t.	Post-temporal.
s.cl.	Supraclavicular.
cl.	Clavicle.
p.cl.	Postclavicular.
i.cl.	Infra-clavicular.

Plate III.

Fig. 1. Restored figure of *Eurynotus crenatus*, Ag. From a large suite of specimens in the Museum of Science and Art, Edinburgh, and other collections.

Fig. 2. External surface of one of the anterior flank scales of the same species; magnified four diameters. Burdiehouse.

Fig. 3. Internal or attached surface of a similar scale.

Fig. 4. External surface of a scale from a position further back on the side of the body; magnified four diameters. West Calder.

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* I have already (Mem. Palæontogr. Soc., 1877) stated my reasons for placing the Palæoniscidæ and consequently also the Platysomidæ rather in the Acipenseroid than in the Lepidosteoid suborder of Ganoids. To reopen this question is, however, beyond the scope of the present essay.

Fig. 5. External surface of a scale from the commencement of the tail pedicle; magnified four diameters. Burdiehouse.

Fig. 6. Internal surface of a similar scale.

Fig. 7. One of the V-shaped ridge-scales of the tail.

Fig. 8. Scales from the side of the caudal body-prolongation.

Fig. 9. Inner aspect of similar scales.

Fig. 10. Internal surface of maxilla of *Eurynotus crenatus;* magnified two diameters. From Burdiehouse.

Fig. 11. Internal surface of maxilla of an *Eurynotus* (E. fimbriatus ?); natural size. From South Queensferry.

Fig. 12. Oral aspect of a pterygoid bone, found lying on the same slab with the last, and along with numerous scales of *Eurynotus;* natural size.

Fig. 13. Outer, or sculptured surface of the maxilla of an *Eurynotus,* from a disjointed specimen; natural size. From Loanhead.

Fig. 14. Internal surface of a similar maxilla; enlarged one-half. From the same locality.

Fig. 15. Palatal teeth of *Eurynotus,* showing the worn or "dimpled" aspect, magnified four diameters. From the same locality.

Fig. 16. Sketch of the left clavicle of *Eurynotus.*

Fig. 17. Reduced outline of the specimen of *Benedenius Deneensis,* figured in Prof. De Koninck's "Faune de calcaire carbonifère de la Belgique," pl. ii.

PLATE IV.

Fig. 1. *Mesolepis scalaris,* Young; natural size. From a specimen from Fenton, Staffordshire, in the collection of J. Ward, Esq., F.G.S. Longton.

Fig. 2. External surface of a scale from the flank of *Mesolepis scalaris;* magnified two diameters.

Fig. 3. Internal aspect of a scale from the flank of the type specimen of *Mesolepis Wardi*, Young; magnified three diameters.

Fig. 4. Internal surface of a scale from the same specimen, situated opposite the origin of the anal fin; magnified three diameters.

Fig. 5. Internal surface of another scale situated near the last; magnified three diameters.

Fig. 6. Sketch of maxilla and mandible of a specimen of *Mesolepis,* in the collection of Dr Rankin of Carluke; magnified two diameters.

Fig. 7. Three teeth from the mandible of the same specimen; magnified twenty diameters.

Fig. 8. Mandibular teeth of *Mesolepis micropterus,* Traq.; magnified eighteen diameters.

Fig. 9. Restored outline of the head and external cranial bones of *Mesolepis.*

Fig. 10. Head of *Eurysomus macrurus,* Ag. sp.; natural size. From a specimen from Midderidge, in the Museum of Science and Art, Edinburgh.

Fig. 11. Three mandibular teeth in the same specimen; magnified five diameters.

Fig. 12. Outline of the bones of the head as exhibited in the only known specimen of *Wardichthys cyclosoma,* Traq.

Fig. 13. Scales from the lateral line of *Wardichthys cyclosoma;* magnified two diameters.

Fig. 14. Internal surface of a flank scale of *Wardichthys*; magnified two diameters.

Fig. 15. Several scales from near the ventral margin of *Wardichthys;* magnified two diameters.

PLATE V.

Fig. 1. Restored figure of *Cheirodus granulosus*, Young sp. From a suite of specimens from North Staffordshire, in the collection of J. Ward, Esq., F.G.S.

Fig. 2. Pterygo-quadrate apparatus of the same species, showing three constituent elements; natural size. North Staffordshire.

Fig. 3. Pterygoid bone, separate, seen from the oral aspect. North Staffordshire.

Fig. 4. Maxilla, seen from the internal aspect, showing the supermarginal band of tooth-like tubercles. North Staffordshire.

Fig. 5. Maxilla, seen from the external aspect.

Fig. 6. Splenial element of mandible, inner or oral aspect. North Staffordshire.

Fig. 7. The same bone from the outer aspect.

Fig. 8. The same bone, seen from above.

Fig. 9. Dentary element of the mandible of a smaller specimen, seen from the outer aspect; the external layer of the bone injured in the middle. Manchester Coal Field.

Fig. 10. Diagrammatic restoration of the palato-quadrate, mandibular, and opercular arrangements in *Cheirodus*, as seen from the inner aspect.

Fig. 11. Interoperculum, seen from the inner aspect. Manchester Coal Field.

Fig. 12. Clavicle, seen from the inner aspect. Manchester Coal Field.

Fig. 13. External aspect of a flank scale belonging to a very large disjointed specimen; natural size. Manchester Coal Field.

Fig. 14. Inner aspect of a similar scale.

PLATE VI.

Fig. 1. Restored outline of *Platysomus striatus*, Ag.

Fig. 2. Scale from the flank of *Platysomus striatus;* magnified two diameters.

Fig. 3. Scale from the flank of *Platysomus parvulus*, Ag.; magnified two and a-half diameters.

Fig. 4. Internal surface of a similar scale.

Fig. 5. Restored outline of *Platysomus parvulus*, Ag.; the scales of the body omitted. From a suite of specimens in the collection of J. Ward, Esq., F.G.S.

Fig. 6. Roof bones of the posterior part of the top of the head of *Platysomus parvulus*, as shown in an ironstone cast of their inner surfaces. Fenton, Staffordshire.

Fig. 7. Median superethmoidal and anterior frontal bones of the same species; magnified two diameters.

Fig. 8. Preoperculum of *Pl. parvulus*, internal aspect; magnified two diameters.

Fig. 9. Maxilla of *Pl. parvulus;* magnified two diameters.

Fig. 10. Branchiostegal ray, detached, of *Pl. Forsteri*, Hancock and Atthey.

Fig. 11. Maxillary teeth of *Pl. parvulus;* magnified fifteen diameters.

Fig. 12. Restored outline of the bones of the outside of the head and shoulder girdle of *Palæoniscus Freieslebeni*, Ag.

Fig. 13. Restored outline of the bones of the outside of the head of *Dapedius*.

Fig. 14. Scales from the flank of *Gyrodus frontatus*, Ag.; seen from the inner surface, and magnified two diameters.

Fig. 15. Scales from the caudal region of the same species, also seen from the inner aspect.

Fig. 16. Scales of *Palæoniscus Freieslebeni;* seen from the inner aspect, and magnified six diameters.

XI.—*The Anatomy of the Northern Beluga* (Beluga catodon, *Gray;* Delphinapterus leucas, *Pallas*) *compared with that of other Whales.* By MORRISON WATSON, M.D., F.R.S.E., and ALFRED H. YOUNG, M.B., &c., of the Owens College, Manchester. (Plates VII. and VIII.)

(Read 21st April 1879.)

During the spring of 1878, owing to the enterprise of Mr FARINI, English naturalists had the rare opportunity of inspecting three living specimens of the northern Beluga or white whale. Descriptive accounts of their capture off the coast of Labrador, and likewise of the methods which, successfully carried out, ensured their safe transmission to this country, appeared at the time in various periodicals.* On the arrival of the whales in England, one was forwarded to the Pomona Gardens, Manchester, where it was placed in a large tank for purposes of exhibition. Though apparently adapting itself to its new home, the whale never appeared to recover from the combined effects of its capture and compulsory voyage; but growing rapidly worse, its condition became so precarious that it was deemed advisable to send it to Blackpool, in the hope that the advantages of a marine aquarium might prove beneficial. Notwithstanding every precaution, however, the whale did not reach its destination, but succumbed on the way.

On hearing of its death, Mr FARINI, with great courtesy, placed the carcase at our disposal. Unfortunately, a misunderstanding arose as to its locality, so that an unavoidable delay necessarily ensued, during which the railway authorities, naturally anxious to get rid of the rapidly putrefying mass, sent the whale to a boiling-down yard, whence it was not rescued until it had to some extent been mutilated.

The body, therefore, when it came into our possession, was neither so perfect nor so fresh as was necessary for an investigation of its entire anatomy, and on this account a myological description of the specimen could not be attempted; consequently our observations, which, so far, have been confined to the soft parts, relate chiefly to the visceral anatomy.

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* An interesting account both of this and of a prior attempt to introduce whales into England was issued in pamphlet form by Mr H. LEE, F.L.S., &c.

The anatomy of Beluga has previously engaged the attention of Dr BARCLAY[*] in this country, and of Professor WYMAN[†] in America. The descriptions of both these anatomists are, however, so very incomplete, even in respect of the few structures commented upon, that we are enabled, whilst supplementing their observations, to record also the result of the investigation of several parts hitherto unnoticed, and to complete a detailed account of the whole of the viscera. The external characters of the white whale being already well known from the description of Drs BARCLAY and NEILL, a further reference to them is rendered superfluous.

On such points as it has seemed desirable, our description of the soft parts has been supplemented by means of illustrations sketched by one of ourselves from recent dissections; these, we trust, will render this memoir of more value to future observers.

Dr BARCLAY's specimen, a nearly adult male, was shot in the Firth of Forth during the year 1815. Prior to this two young Belugas had been cast ashore near Thurso; whilst subsequently but a single instance of its occurrence on the British coast is recorded, being that of a specimen which was stranded on one of the Orkney Islands in 1845.

The Beluga examined by us was a female, which, from its size, and from the condition of its epiphysial ossifications, we judged to be three-fourths grown. Teeth were present in both the upper and lower jaws. Its dimensions were as follows:—

	FT.	IN.
Length from the truncated extremity of the snout (following the curvature of the spine) to the notch in the middle line of the tail,	8	7½
Length from snout to blow hole, ...	0	11¼
Breadth of blow hole, ...	0	2½
Length from snout to eye, ...	0	9
From snout to base of pectoral fin, ...	2	2
Length of pectoral fin, ...	0	10
Breadth of pectoral fin at the base, ...	0	4
" " broadest part, ...	0	5½
Breadth of caudal fin, ...	1	8½
Depth of notch in caudal fin, ...	0	1¼
From junction of pectoral fin with body over dorsum, to corresponding part on opposite side, ...	2	7

In the course of this paper frequent reference has necessarily been made to the writings of previous observers. To avoid the necessity of numerous lengthy

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[*] "Account of a Beluga or White Whale," Memoirs of the Wernerian Natural History Society, vol. iii.

[†] "Description of a White Fish or White Whale" (*Beluga borealis*), Boston Journal of Natural History, vol. vii.

footnotes, we subjoin a list of the principal memoirs which have been consulted with regard to the soft parts of other cetaceans. In the text, the source of all references is specified by stating the page of the article referred to along with its numerical designation according to the list here given :—

I. Carte and Macalister : "On the Anatomy of *Balænoptera rostrata.*" Phil. Trans., 1868, part i.

II. Murie : "On the Organisation of the Caaing Whale" (*Globiocephalus melas*). Trans. Zool. Soc., vol. viii.

III. Wyman : "Description of a White Fish or White Whale" (*Beluga borealis,* Lesson). Boston Jour. of Nat. Hist., vol. vii.

IV. Jackson : "Dissection of a Spermaceti Whale, and three other Cetaceans." Boston Jour. of Nat. Hist. vol. v.

V. Murie : "On *Lagenorhynchus albirostris.*" Jour. Linn. Soc., Zoology, vol. xi.

VI. Macalister : "On some Points in the Anatomy of *Globiocephalus Svineval.*" Proc. Zool. Soc., 1867.

VII. Perrin : "Notes on the Anatomy of *Balænoptera rostrata.*" Proc. Zool. Soc., 1870.

VIII. Barclay and Neill : "Account of a Beluga or White Whale." Memoirs of the Wernerian Soc., vol. iii.

IX. Turner : "A Contribution to the Anatomy of the Pilot Whale (*Globiocephalus Svineval*)." Jour. of Anat. and Phys., vol. ii.

X. Murie : "On Risso's Grampus" (*G. Rissoanus*). Jour. of Anat. and Phys., vol. v.

XI. Fischer : "On Grampus griseus." Annal de Science Naturelle (5th Series), Tome viii., Zoology, 1869.

XII. Flower : "On Physalus Antiquorum." Proc. Zool. Soc., 1865.

XIII. Abernethy : Phil. Trans., 1796.

XIV. Gray's Chinese Repository, 1838.

XV. Stannius : "Beschreibung der Muskeln des Tummlers." Müller's Archiv. f. Anat., 1849.

XVI. Hunter : "On the Economy and Structure of Whales." Phil. Trans., 1787.

XVII. Turner : "An Account of the Great Finner Whale (*Balænoptera Sibbaldii*) stranded at Longniddry." Trans. Roy. Soc. Edin., vol. xxvi.

XVIII. Meckel : Anatomie Comparée.

XIX. Mayer : "Uber den bau des Organes der Stimme." Nova, Acta Acad., Leo-Car., 1851, vol. xxiii.

XX. Recent Memoirs on the Cetacea, by Eschricht, Reinhardt, Lilljeborg. Edited by Flower, Ray Soc.

XXI. Owen : Anatomy of Vertebrates.

XXII. Hunter's "Essays and Observations." Edited by Owen, vol. ii.

XXIII. Gulliver : "Notes on a Cetaceous Animal stranded on the North-East Coast of Ireland." Proc. Zool. Soc., 1853.

XXIV. Sandifort: "Nieuwe verhandelingen, Koninklijk nederlandsche Instit.," 1831.
XXV. Burmeister: "On the Anatomy of *Pontoporia Blainvillii*." Proc. Zool. Soc., 1867.
XXVI. Fleming: "Description of a small-headed Narwhal cast ashore in Zetland." Memoirs of the Wernerian Soc., vol. i.
XXVII. Knox: Catalogue of Anatomical Preparations of Whales. Edin., 1838.
XXVIII. Eschricht: "Die Nordischen Wallthiere." 1848.
XXIX. Malm: "Monographie illustrée du Baleinoptère." Stockholm, 1867.
XXX. Major: "On the Structure of the Brain of the White Whale." Jour. of Anat. and Phys., 1879.
XXXI. Cuvier: Leçons d'Anatomie.
XXXII. Vicq. D'azyr: "Memoirs sur la voix." Mem. de l'Acad. des Sciences, 1779, pl. vii. figs. 1, 2, and 3.
XXXIII. Turner: "Further Observations on the Stomach of Cetacea." Jour. of Anat. and Phys., vol. iii.
XXXIV. Murie: "On the Anatomy of a Fin Whale" (*Physalus antiquorum*). Proc. Zool. Soc., 1865.
XXXV. "Cyclopædia of Anatomy." Art. *Cetacea*, vol. i.
XXXVI. Home: "On the Structure of the different Cavities of the Stomach of the Whale." Phil. Trans., 1807, part i.
XXXVII. Heddle: "On a Whale of the genus *Physalus*." Proc. Zool. Soc., 1856.
XXXVIII. Crisp: "On some Parts of the Anatomy of the Porpoise (*Phocœna communis*)." Proc. Zool. Soc., 1864.
XXXIX. Murie: "On the Saiga Antelope (*Saiga tartarica*)." Proc. Zool. Soc., 1870.
XL. Flower: Trans. Zool. Soc., vi. p. 115.
XLI. Burmeister: "On a New Cetacean." Ann. and Mag. of Nat. Hist., 1866, third series, vol. xvii.

Digestive Organs.

Tongue.—The tongue, from the anterior border of the hyoid bone to the tip, measures 9 inches in length and has a uniform breadth of 2¼ inches. The anterior 4 inches of the organ is alone clearly defined from the floor of the mouth by means of a well-marked groove which indicates the separation between these parts. Posteriorly this groove disappears, so that the posterior half of the tongue forms the floor of the mouth, its upper surface being quite continuous with that of the cheek. In form, the tongue reminds one to some extent of the sole of a shoe, being flattened from above downward, with its anterior extremity uniformly rounded. Its upper surface is flat and smooth, and its anterior or free margin is provided with numerous flattened foliaceous projections of the mucous membrane. The posterior two thirds of the upper surface present numerous little depressions resembling pin holes, which become much larger toward the root of the organ. These openings, which are also present in numbers on the region of the cheek, indicate the ducts of numerous mucous glands which lie immediately underneath the mucous membrane. The tongue of Beluga does not appear to differ much from that of other toothed whales. In *Globiocephalus intermedius,* according to MACALISTER,[*] not only the tip, but also the margins of the organ are free, whereas in Beluga the latter are attached along nearly their whole length. Dr MURIE[†] refers to the presence of a distinct frœnum in *Globiocephalus melas,* but this structure is not recognisable in Beluga. In respect of the very close attachment of the tongue to the sides and floor of the mouth, Beluga appears to approach the whalebone whales, in which the organ is perfectly immobile, and to differ in various degrees from the other toothed species, in nearly all of which greater mobility is conferred upon this organ than in the white whale. The presence of fringe-like processes of mucous membrane on the margins of the tongue did not escape the notice of Professor WYMAN[‡] in Beluga. They appear to be somewhat exceptional among the Cetacea. Dr JACKSON,[§] however, speaks of the tongue of the sperm whale as being provided anteriorly with "numerous fissures and granulations," an arrangement which appears to resemble closely that described above in Beluga. Their presence is also recorded by Dr MURIE[||] in *Lagenorhynchus albirostris.*

Salivary Glands.—The presence of these is doubtful. At the same time, it is well to state that we detected an apparently glandular body which occupied the usual position of the sub-maxillary gland. In size it resembled the gland of the same name in the human subject, and what we took to be a duct could be traced upward into the muscular substance of the tongue. The unsatisfactory condition of the parts, however, prevented its termination being clearly defined. MACALISTER[¶] searched in vain for any trace of a salivary gland in *Globiocephalus,* but a rudimentary parotid was noticed by him in *Balænoptera rostrata.*[**]

Tonsil and Uvula.—On opening the pharynx no trace of either of these structures could be distinguished. Such is also the case according to MURIE[††] and MACALISTER[‡‡] in *Globiocephalus melas.*

Pharynx.—The muscular wall of the pharnyx is separable into three distinct constrictors. The *superior constrictor* consists of two planes of fibres, readily separable one from another. These may be distinguished as the superficial and the deep. The *superficial* fibres arise in front of the blow hole, but, unfortunately, their exact attachment to the bone could not be made out,

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[*] I. p. 230.
[†] II. p. 251.
[‡] III. p. 610.
[§] IV. p. 140.
[||] V. p. 143.
[¶] VI. p. 480.
[**] I. p. 222.
[††] II. p. 253.
[‡‡] VI. p. 478.

as the pharnyx had been separated from the skull. These fibres pass backward on the side of the pharnyx, and become continuous with those of the opposite side behind that tube. They intermingle also with the fibres of the stylo-pharyngeus. The *deeper* fibres lie immediately under cover of the mucous membrane of the pharynx, and are most easily dissected from the inside of the tube. They form a constrictor or sphincter of the spiracle, and surround that cavity almost to its external opening. They are aggregated so as to form a muscular ring of great strength which surrounds the lower aperture of the spiracle. In other words, we have in these last mentioned fibres a means whereby the spiracular cavity may be shut off from the pharynx, whilst the upper fibres of the muscle may be regarded as being of service in producing alterations in the form and capacity of that chamber.

The *Middle Constrictor* arises from the posterior border of the thyro-hyal bone. The fibres pass backward, and blend behind the pharynx with those of the superior and inferior constrictors.

The *Inferior Constrictor* arises from the whole length of the superior border of the thyroid cartilage, including its posterior horn. It does not take any attachment to the cricoid cartilage. The fibres pass backward, and unite with those of the opposite side along the middle line posteriorly. A strong median raphé, to which the fibres of the constrictor muscles are attached, extends along the posterior aspect of the pharynx.

Stylo-pharyngeus Muscle arises from the base of the stylo-hyal bone. The fibres ascend obliquely upward and forward, and blend with those of the superior constrictor. It is a strong riband-like muscle, and when in action pulls the bag of the pharynx backward.

Palato-pharyngeus Muscle.—This muscle, which is described by both MURIE[*] and MACALISTER[†] in *Globiceps,* could not be distinguished by us in Beluga.

The arrangement of the pharyngeal muscles above described closely resembles that observed by MACALISTER[‡] in *Globiocephalus.* The deeper layer of our superior constrictor evidently corresponds to the constrictor of the posterior nares of that author. According to him, in *Globiocephalus* the middle constrictor arises as in Beluga from the thyro-hyal bone, whilst Dr MURIE[§] found it arising from the thyroid cartilage. In Beluga the origin of the inferior constrictor is confined to the thyroid cartilage, which is in accordance with Dr MURIE's observations on *Globiocephalus.* MACALISTER,[‡] on the other hand, observes that its fibres take an additional attachment to the cricoid cartilage in the latter species. *Balænoptera rostrata*[‖] differs from both in the rudimentary condition of the superior constrictor.

Œsophagus.—This tube measures 10 inches in length. Its mucous membrane

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[*] II. p. 254.

[†] VI. p. 480.

[‡] VI. p. 479.

[§] II. p. 254.

[‖] I. p. 245.

is thrown into well-marked longitudinal rugæ. It presented no trace of the glandular apertures described by Dr MURIE* in *Globiocephalus melas*, but it is possible that the somewhat unsatisfactory state of the part prevented the recognition of these in Beluga.

Stomach—External appearance.—When this viscus is distended with air and its exterior examined, the œsophagus appears to terminate at the junction of its first and second compartments, leading to the belief that it communicates with both. As we shall presently see, this appearance is deceptive, the œsophagus terminating in the first compartment, and in it alone. The latter, as in several other cetacea, resembles much the paunch of the ruminant. It measures 11 inches in length and 9 inches in greatest breadth. When viewed from below it appears to be of an oval form, an appearance which is due to the fact that when the parts are in their natural position the first is to some extent overlapped by the second compartment. When the latter is drawn aside the paunch is seen to be cordiform rather than oval, its rounded apex projecting horizontally backward. The *second* compartment measures 12 inches in length and 4½ inches in greatest breadth. It is oval in form, and tapers slightly to its posterior extremity which is closely applied to the wall of the cavity on its right. The *third* stomach is not visible externally, and consequently any description of the organ based upon the mere examination of its exterior is altogether misleading, so far as an accurate determination of the number of its cavities is concerned. The *fourth* stomach is reniform, and when distended measures 5 inches in length and 2½ in breadth. It is separated externally by a well-marked sulcus from the *second* compartment, which lies to its left. The *fifth* compartment, 13 inches in length, recalls to mind the form of the ruminant abomasum. Its left extremity is the larger, the diameter of its cavity diminishing slightly from its commencement to its termination. It extends for 9 inches to the right, and then curves upon itself to become continuous with the duodenum at the pylorus.

Interior of Stomach.—When the stomach is opened the œsophagus is seen to terminate in the first compartment: the œsophageal opening is of the same diameter as the rest of the tube. Immediately below, and slightly to the right of this aperture, is the orifice by means of which the first communicates with the second stomach. Its diameter is rather less than that of the œsophagus. A well-marked fold of mucous membrane extends from the inferior margin of the œsophageal opening, obliquely backward and to the right, and subsides on the superior wall of the second compartment after forming the superior lip of the aperture of communication between the first and second stomachs. This fold appears to correspond to the posterior lip of the œsophageal groove which in

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* II. p. 256.

the ruminant extends from the œsophageal opening to the psalterium; it is so arranged as to form the inferior lip of the cardiac aperture and the superior lip of that between the first and second stomachs. The mucous lining of the first compartment is thick, and apparently devoid of glands. Its epithelial coat is corneous, and thrown into numerous anastomosing rugæ, which are irregularly disposed, and together present an arrangement not unlike that of the cerebral convolutions. This convoluted appearance of the mucous membrane is most distinctly marked toward the base of the stomach, and disappears altogether at its apex, the lining membrane in the latter situation being uniformly smooth and destitute of rugæ. The mucous membrane lining the channel of communication between the first and second stomachs is similar in character to that just described, but changes abruptly so soon as it enters the latter, where it assumes a soft and glandular character.

The *second* gastric compartment is provided with two apertures. Of these the first is situated on its left wall, an inch and a half from the œsophageal orifice, and opens up a communication between the first and second stomachs. It is of size sufficient to admit of the passage of two fingers. By means of the second opening, which is situated on the right wall of the cavity, three inches from its posterior extremity, the second communicates with the third compartment. This orifice is circular in form, and its diameter does not exceed half an inch. The mucous membrane of the second cavity is thick, soft, and glandular in character. It is thrown into several colossal rugæ, the largest of which measures one inch in height. They are more pronounced on the inferior and left than on the superior and right walls of the cavity, and are soft, glandular, and non-corneous, differing in these respects from the corresponding structures of the first compartment. They follow an irregularly serpentine course, giving off numerous secondary folds, the result being a generally convoluted arrangement of the mucous membrane not unlike that which we have described in the first stomach, but rather more open in character.

The *third* compartment is not recognisable externally. According to Dr Murie,[*] it is to be regarded simply as a canal of communication between the second and third (our fourth) stomachs. To us, for reasons to be presently stated, it appears to form a true subdivision of the stomach, and we shall describe it as such. It is situated between second and fourth compartments, and measures 3 inches in length and 2½ in greatest breadth. It is provided with two apertures, of which one, already described, is placed upon its left wall one inch behind its anterior cul-de-sac, and communicates with the second stomach; whilst the other, situated on the posterior extremity of the cavity, measures ¼ of an inch in diameter, and communicates with the compartment on its right. The mucous membrane is soft and smooth, resembling in these respects

[*] II. p. 258.

that of the fourth and fifth stomachs, and differing from that of the first and second.

The interior of the *fourth* stomach corresponds exactly in form to that of its exterior. On its left wall, two inches from its posterior extremity, is the opening above described, by means of which this compartment communicates with that on its left. The opening into the fifth stomach is circular in form, and measures about half an inch in diameter. It is placed in the anterior wall of the cavity. The mucous lining is soft, uniformly smooth, and destitute of rugæ.

The cavity of the *fifth* stomach commences by a blind extremity or cul-de-sac, on the posterior wall of which, and two inches from its deepest part, is placed the opening by means of which the fourth communicates with the fifth stomach. The duodenal extremity of the latter is narrower than any other part, and is furnished with a well-marked ring-like pyloric valve, in the centre of which is a circular opening one-fourth of an inch in diameter. The diameter of this compartment diminishes gradually from its commencement to its termination, the latter being marked externally by a slight constriction. Its lining membrane resembles that of the fourth stomach, being smooth and devoid of rugæ. None of the openings between the different gastric compartments presents the slightest trace of a valve. PERRIN[*] describes the canal-like communication between the second and third stomachs of *Balænoptera rostrata* as being provided with a valve at each extremity.

From what has been said, it will be seen that in respect of the number of gastric cavities in Beluga, our observations agree with those of Professor WYMAN,[†] and differ from those of BARCLAY.[‡] The latter author describes and figures only four compartments in this species, and an examination of the drawing which he appends to his description shows conclusively that he failed to recognise the third compartment above described. This is less to be wondered at, seeing that the cavity referred to is not distinguishable externally from the second and fourth, between which it lies. Dr BARCLAY, however, describes correctly the character of the mucous membrane of such compartments as he examined.

An exact comparison of the stomach of Beluga with that of other cetaceans is, in the present state of our knowledge, well-nigh impossible, by reason of the diversity of statement which obtains with regard to the number of compartments in one and the same species according to different authors. In proof of this, we have thought it right to append the following tabular view of the observations of various anatomists who have examined the stomach of one or more species of cetacea :—

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[*] VII. p. 805.

[†] III. p. 607.

[‡] VIII. p. 382.

Toothed Whales.

Globiocephalus.	Grampus.	Delphinus.	Monodon.	Platanista.	Hyperoodon.	Zyphiorrynchus.	Catodon.	Phocæna.
Sp. Svineval. 5 Turner. 5 Jackson. 4 Murie. 2 Gulliver.	Sp. griseus. 5 Fischer.	Sp. tursio. 4 Hunter.	Sp. monoceros. 5. Meckel.	Sp. gangetica. 5 Cuvier.	Sp. bidens. 7 Hunter.	Sp. cryptodon. 8 Burmeister.	Sp. ? 3 Jackson.	Sp. communis. 4 Turner. 4 Hunter. 3 Huxley. 4 Jackson. 4 Crisp.
	Sp. ? 5 Hunter.	Sp. ? 5 Turner. 5 Jackson.						
Pontoporia. 4	Sp. Rissoanus. 5 Murie.							

Whalebone Whales.

Balænoptera Sibbaldii.	Physalus antiquorum.	Balænoptera rostrata.
at least 4 Turner.	4 Murie.	5 Carte and Macalister. 5 Hunter. 4 Perrin.

The diversity of statement brought out in the foregoing table regarding matters of fact is probably explicable on the supposition that different anatomists hold different views with regard to what ought to be considered a true gastric cavity, some regarding the duodenal dilatation so common among the cetacea as a true stomach, whilst others again look upon the third compartment described above as merely a communicating passage between the neighbouring cavities.

Among the upholders of the latter view, we may mention the name of Dr JAMES MURIE, who, in his elaborate monograph on *Globiocephalus,* adduces the following arguments in its favour. Dr MURIE* says:—"I look upon it (the cavity in question) only as a communicating canal, because of its diminutive capacity and diameter; because it is not at all a free chamber, but, strictly speaking, like the end of a bile duct, a tunnel burrowing its whole length betwixt the adjoining walls of II. and IV.; because of its smooth mucous membrane, showing few or no traces of digestion taking place therein; because the other four chambers agree with what obtains in *Phocæna, Grampus,* and *Balænoptera,* and the two latter also offer an incipient structure of a similar kind, and corresponding in situation; and, lastly, because I regard certain of the so-called stomachs of certain Cetaceans (*Hyperoodon,* for example, with six or seven) as

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* II. p. 258.

only canals between the true digestive chambers, as is shown above." Dr MURIE's opinion upon a subject of this kind is undoubtedly entitled to much weight, but we may be excused if we feel compelled to doubt the cogency of the arguments adduced in support of it. The diminutive size of what we regard as the third stomach in Beluga and *Globiocephalus* does not, it seems to us, militate against the view that the cavity ought to be regarded as a true stomach, inasmuch as we know that in many animals, *e.g.*, birds, the true digestive juices are secreted by a glandular patch of extremely limited size as compared with the bulk of the stomach as a whole. That the cavity in question is not a free chamber, we are inclined to doubt, at least so far as Beluga is concerned; for, as the preceding description distinctly shows, the cavity is prolonged as a cul-de-sac in front of the most anterior of the two openings, by means of which it communicates with the neighbouring compartments. Add to which that in both Beluga and *Globiocephalus* the apertures of communication between the third compartment on the one hand, and the second and fourth on the other, are much narrower than the cavity itself, and it appears to us that the analogy between the latter and the passage of the bile duct through the walls of the intestine is satisfactorily disposed of. Professor TURNER [*] observes in his description of the stomach of *Globiocephalus*, that the mucous membrane of the third compartment "presented a few faintly-marked folds and gland orifices." The presence of the latter appears to us to be incompatible with Dr MURIE's observation of the "smooth mucous membrane showing few or no traces of digestion taking place therein." The fact that both *Grampus* and *Balænoptera* present traces of a similar structure, tends rather to support the view that Dr MURIE's so-called passage ought to be regarded as a true stomach, inasmuch as it is difficult to understand why, in the case of these different cetacea, an elongated passage occupying a definite position with reference to the other compartments should be substituted for the simpler arrangement, by means of which the first and second or the fourth and fifth compartments communicate with each other, if its function be merely that of a conduit, and not that of a true digestive cavity. Taking all the facts into consideration, therefore, we incline to the view that the third gastric cavity above described ought to be regarded as a true digestive organ rather than as a mere passage between the neighbouring compartments,—a view in which we are supported by the authority of both Dr JACKSON[†] and Professor TURNER,[‡] founded upon an examination of the stomach of *Globiocephalus*.

Be this as it may, the table serves to show that in the majority of the toothed whales, in accordance with the observations of the greater number of anatomists, the stomach is divided into five distinct compartments. In this

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[*] IX. p. 72.

[†] IV. p. 160.

[‡] IX. p. 73.

respect, therefore, Beluga agrees with these. The description of the form of the stomach in different species is not sufficiently exact to enable us to come to any conclusion with regard to the relation in which the latter stand to one another; but founding upon Dr MURIE'S[*] observation that the second and fourth compartments of the stomach of RISSO'S Grampus differ from those of *Globiocephalus* in respect of their more elongated and less globular form in the former, we may state that so far as this organ is concerned, Beluga appears to be more closely related to *Grampus* than to *Globiocephalus.*

In *Grampus Rissoanus,* however, Dr MURIE observes that the opening, by means of which the second communicates with the third stomach, is situated close to that between the first and second compartments; whereas in Beluga, as we have seen, they are separated by an interval equal to two-thirds of the length of the second stomach. In this respect Beluga agrees with *Globiocephalus* rather than *Grampus.*

We have previously directed attention to the presence of a fold of mucous membrane, extending between the œsophageal aperture of the first and the superior wall of the second compartment of the stomach in Beluga, and remarked upon the resemblance which it bears to the superior lip of the œsophageal groove of the ruminant stomach. A similar observation has been made by Dr MURIE in his description of *Globiocephalus.* Whilst directing attention to the presence of this fold, however, we would wish to avoid attributing to it any physiological significance in tracing an analogy between the stomach of the ruminants and that of the cetaceans. Professor TURNER,[†] founding on his observation that in *Globiocephalus* the œsophagus communicates freely with both the first and second stomachs, is of opinion "that a provision would seem to exist in this animal for permitting a process of rumination as far as regards the contents of these two compartments, and an additional link is established between the ruminant and cetacean stomach."

With this opinion we are unable to agree—Firstly, Because in the ruminants, in which alone do we know anything positive regarding the process of rumination, the food, after passing through the first, is regurgitated from the *second* stomach, and subsequent to undergoing a second process of mastication is passed into the *third* stomach, this transference of the bolus being effected by means of the œsophageal groove. In the cetacea, on the other hand, at least in Beluga and *Globiocephalus,* the œsophageal groove is incomplete, and is therefore wholly inadequate to perform the function of a canal, by means of which the food could be transferred from one compartment of the stomach to another. It, moreover, differs from the corresponding structure in the ruminant stomach, inasmuch as it terminates in the *second* compartment of the viscus instead of

[*] X. p. 132.

[†] IX. p. 72.

the *third.* On the supposition, therefore, that a process of rumination takes place in the cetacea, we are compelled to assume that the food is regurgitated from either the first or *second* compartment, to be afterwards carried back into the same,—a process which, if it ever takes place, is essentially different to that which occurs in the true ruminants. Secondly, The strictly animal diet of the toothed whales may further be advanced as an argument against this view, the nature of the food precluding the necessity of a process which, so far as positive knowledge goes, is strictly confined to truly herbivorous mammalia. Thirdly, The form and arrangement of the teeth in the zoophagous cetacea is such as seems but ill-adapted for carrying out their part in the supposed function of rumination. As M. FISCHER* has well said, when discussing this hypothesis :—" Bon nombre de cétacés (*Balein, Ziphius, Grampus*) sont complétement dépourvus de dents ou n'en possèdent qua l'extrémité du rostre."

Intestine.—The gut from pylorus to anus measures 54 feet in length. At its commencement it is wider than elsewhere, its diameter here being double that of any other part of the intestine. This dilated portion measures 5 inches in length, and receives the previously united hepatic and pancreatic ducts which open into it 4 inches from the pylorus, after lying in the wall of the gut for a distance of 2 inches. Immediately beyond the duodenal dilatation the gut, when flattened, measures 2¼ inches in breadth, whilst at its rectal extremity this measurement diminishes to 1¼ inch. The intestinal tube, therefore, decreases from its commencement to its termination, but the calibre of its lower half is somewhat irregular in consequence of constrictions which occur every here and there. There is no trace of any subdivision of the gut into small and large intestines, and the cæcum is entirely absent. The intestine is attached to the superior abdominal wall by a mesentery measuring 9 inches in breadth.

The mucous membrane lining the duodenal dilatation is uniformly smooth and destitute of valvulæ conniventes. One inch beyond the point of entrance of the combined hepatic and pancreatic ducts, however, the valvulæ begin to appear. At first small and faintly marked, they rapidly become valvulæ and form circular valve-like projections, measuring ¾ of an inch in depth, attached to the entire circumference of the gut. These large folds alternate with others of smaller size, which do not extend round the entire gut. The larger valvulæ are found along the upper half of the intestine, but below this they become smaller, and are less regularly disposed. In the lower 9 feet of the gut they are scarcely recognisable. The mucous membrane beyond the duodenum possesses a delicate, soft, and velvety appearance. Beyond the pyloric valve the surface

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* XI. p. 307.

of the mucous membrane presents a cribriform aspect, due to the presence of a number of little apertures which are visible to the naked eye. These openings, which do not extend farther than 2 inches from the pylorus, appear to be the orifices of glands, in all probability corresponding to those of Brunner in other mammals, but the somewhat unsatisfactory state of the part prevented the recognition of such by means of the microscope. The Peyerian patches are eighteen in number. They are large, irregular in form, and the long diameter of each coincides with that of the intestine. They are mostly situated on the free side of the gut. The largest patches, measuring for the most part about 9 inches in length, are found near the duodenal extremity of the intestine. Those of the lower half of the gut do not exceed 2 or 3 inches in length. The largest patch of all, however, measuring 16 inches in length, and occupying the entire circumference of the intestine, terminates at a distance of 11 inches from the anus, beyond which point these glands are entirely wanting. The first Peyerian patch is situated 5 feet beyond the pyloric valve.

The intestinal arteries are very regular in their arrangement. They inosculate with one another so as to form a series of vascular arches, the summits of which abut against the wall of the intestine. From these arches numerous branches are given off for the supply of the gut, without the intervention of any secondary arcades. The veins are arranged in a similar manner.

The mesenteric lymphatic glands are aggregated so as to form a mass, measuring 13 inches in length and 3 inches in breadth, surrounding the main trunk of the mesenteric artery. The margins of this mass are irregular in consequence of the presence of outlying processes, which for the most part are prolonged toward the gut, and accompany the main branches of the mesenteric artery. In addition to this glandular mass, isolated lymphatic glands of large size are dispersed here and there between the mesenteric folds of peritoneum. The lymphatic vessels are very numerous, and run in bundles from the walls of the gut to the central glandular mass. They are richly provided with valves, which entirely prevent the passage of injection *toward* the gut, although it passes with the greatest ease in the opposite direction. The neighbouring lymphatic vessels communicate freely with one another.

According to MECKEL,* in the cetacea the length of the intestine is to that of the body as 11 or 12 to 1; but an examination of the accompanying table will show that, except in the case of the porpoise, this estimate is too high :—

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* XVIII. vol. vii. p. 388.

Delphinus orca—
8 to 1, Reinhardt.

[*]*Delphinus delphis*—
6½ to 1, Jackson.

Globiocephalus melas—
9 to 1, Murie.
8 to 1, Jackson.
[*]6½ to 1, Gulliver.

Globiocephalus (*Chinese species*)—
7 to 1, Williams.

Beluga catodon—
6 to 1, Wyman.
6⅓ to 1, Barclay.
6⅓ to 1, W. and Y.

Sperm Whale—
16¼ to 1, Jackson.

Grampus Rissoanus—
7 to 1, Murie.

Ziphiorrhynchus cryptodon—
5 to 1, Burmeister.

Phocæna communis—
11·4 to 1, Cuvier.
14 to 1, Jackson.

Balænoptera rostrata—
5¼ to 1, Perrin.
5¾ to 1, Carte and Macalister.

The table, moreover, shows that in the majority of the toothed whales the intestine relatively to the body is considerably longer than in the whalebone whales, only a single species of the former (*Zyphiorrhynchus*) possessing a relatively shorter alimentary canal than any member of the latter group.

So far as Beluga is concerned, it appears to occupy an intermediate position between the two.

In respect of the duodenal dilatation, Beluga agrees with nearly all the cetacea; and with the other *toothed* whales, in the absence of a cæcum or any distinction between the small and large intestines. Peyerian patches similar to those described in Beluga have been noticed in *Globiocephalus melas*,[†] *Grampus Rissoanus*,[‡] *Balænoptera rostrata*,[§] *Delphinus delphis*,[||] and *Phocæna communis*.[||] In all probability more extended investigation will affirm their presence in all the species of cetacea. The mesenteric lymphatic glands of Beluga agree with those of *Globiocephalus* in the absence of any cavity in their interior resembling that described by ABERNETHY[¶] in *Balæna*.

Liver.—This viscus is of large size and extends from the œsophagus on the left to the curve of the fifth gastric compartment on the right. It measures 16 inches from right to left and 8 inches in greatest breadth from its attached to its free margin. The attached margin is thick and rounded, whilst the free border is thin and sharp. The anterior surface is closely attached to the diaphragm, whilst the posterior is in contact with the second and fifth gastric cavities. It presents no trace of subdivision into a right and left lobe. The organ is enclosed in a strong fibrous capsule, from the deeper aspect of which

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[*] This specimen was fœtal.

[†] II. p. 259.

[‡] X. p. 133.

[§] I. p. 249.

[||] IV. pp. 157 and 169.

[¶] XIII. p. 675.

septal processes pass inward to the hepatic substance. There is no trace of a gall bladder. Neither did we observe any dilatation of the hepatic duct in the wall of the intestine similar to that described by Dr MURIE[*] in *Globiocephalus*. The hepatic duct measures 5 inches in length, and is united with the pancreatic duct an inch and a half before it reaches the wall of the intestine. The combined ducts enter the duodenum 4 inches beyond the pylorus.

In respect of the absence of any trace of subdivision of the liver into a right and left lobe, Beluga appears to differ from almost every cetacean in which that organ has hitherto been described. That this is not an exceptional arrangement, occurring in only a single specimen of the species, appears to be proved by the fact that neither BARCLAY and NEILL nor WYMAN make any mention of distinct hepatic lobes in the specimens which they examined; at the same time, it should be observed that variation in the relative sizes of the hepatic lobes in different individuals of the same species of cetacea does sometimes occur, as is evident from the observations of JACKSON and MURIE upon *Globiocephalus*, in which, according to the former, the right is two or three times larger than the left hepatic lobe, whilst the latter investigator found them to be of the same size. On the other hand, Beluga agrees with all the other cetacea (with the exception of *Globiocephalus chinensis*)[†] in the absence of a gall bladder, and with the majority of the toothed whales,[‡] in respect of the junction of the hepatic and pancreatic ducts previous to their passage through the intestinal wall. In *Globiocephalus*[§] and *Grampus*[||] Dr MURIE describes the hepatic duct as being dilated into a kind of reservoir, where it lies in the wall of the duodenum. No such arrangement was distinguishable in Beluga.

Pancreas.—This organ measures 10 inches in length and $2\frac{1}{2}$ in greatest breadth. It is somewhat flattened from above downward, and its extremities are evenly rounded. It extends from the right side of the apex of the first gastric compartment to the pylorus, and is overlapped on its lower surface by the second cavity of the stomach. Its surface is distinctly lobulated. The duct, as already stated, unites with that of the liver an inch and a half before the latter passes through the intestinal wall.

The pancreas does not present much variety either in respect of form or relations in the cetacea. In Beluga it does not appear to differ in either of these particulars from what has been noticed in the other toothed whales.

Spleen.—This organ is small and cake-like. It is situated directly behind and in contact with the superior surface of the first gastric compartment, and touches the left extremity of the pancreas. It is irregularly rounded, and measures about 3 inches in diameter, with an average thickness of 1 inch.

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[*] II. p. 261.

[†] II. p. 261.

[‡] (In Zyphiorrhynchus these ducts open separately into the duodenum.)

[§] II. p. 261.

[||] X. p. 133.

In respect of its uniformly smooth surface, the spleen in Beluga differs from that of many cetacea, a distinctly lobulated character of that organ being noted by several observers in other species. In several, accessory spleniculi are found, but of these there is no trace in Beluga. These spleniculi, however, appear to be variable within the limits of even the same species. Dr JACKSON[*] describes them as being present in *Globiocephalus*, whilst Dr MURIE,[†] on the other hand, as distinctly affirms their absence. The position of the spleen, lying as it does in relation to the superior aspect of the first gastric compartment, appears to be constant in all forms of the cetacea.

HYOID BONE.

The hyoid bone is composed of the elements usually met with in the cetacea.

The *basi-hyal* measures 2¼ inches in length and the same in breadth between the thyro-hyals. It is hexagonal in form. The posterior border affords attachment to the thyro-hyoid ligament, whilst the anterior articulates with the cerato-hyals. Of the two external borders of either side the anterior is occupied by the origin of the inter-hyoid muscle, whilst the posterior is continuous with the thyro-hyals. The lower surface is slightly convex, and presents a well-marked transverse ridge, to which a number of muscles, elsewhere described, are attached, whilst the upper surface is slightly concave.

Thyro-hyals.—Each measures 2½ inches in length and 1 inch in breadth at the base. Its free extremity is completed by a little cap of cartilage, and a plate of the same substance is interposed between the base of the thyro-hyal and the basi-hyal.

Cerato-hyals are entirely cartilaginous, and measure 1½ inch in length. Each is attached by one extremity through the medium of a capsular ligament to the free end of the stylo-hyal, whilst the other end lies in contact with a loose cartilaginous segment measuring half an inch in thickness, which separates it from the basi-hyal. The cerato-hyal is attached to the segment referred to by means of a fibrous capsule.

Stylo-hyals, measuring 4 inches in length and 1 inch in breadth, are somewhat flattened. Each is strongly curved towards the middle line, and is cartiliginous in its lower half.

MUSCLES OF TONGUE AND HYOID BONE.

By the time the subject came into our possession these muscles had to some extent been destroyed, partly by injury and partly by decomposition. We are, therefore, unable to give so satisfactory a description of them as we could desire. At the same time, we may be permitted to state that such observations as are here recorded are accurate so far as they go.

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[*] IV. p. 163.

[†] II. See plate xxxiii. fig. 35.

Sterno-hyoid Muscle.—Origin cut. The muscle is broad, flat, of great strength, and is inserted partly into a well-marked transverse ridge on the lower surface of the basi-hyal, but chiefly into the whole length of the thyro-hyal bone. It rests by its deeper surface on the sterno-thyroid and thyro-hyoid muscles.

In *Globiocephalus* [*] the muscle is similarly arranged, whilst in *Balænoptera rostrata* [†] its insertion is limited to the basi-hyal bone.

Sterno-thyroid Muscle.—Origin cut. It is inserted into an oblique ridge on the outer surface of the thyroid cartilage, much as in the human subject.

In *Globiocephalus* [‡] the muscle agrees exactly with this description. In *Balænoptera rostrata* [§] it is absent.

Thyro-hyoid Muscle is very strong. It arises from the oblique line above mentioned, of the thyroid cartilage. The fibres diverge as they pass forward, and are inserted into the whole length of the thyro-hyal as well as into the posterior border of the basi-hyal bone. The muscles of opposite sides are in contact at their origins, but diverge so as to leave an interval at their insertion.

In *Globiocephalus,* Macalister [||] observes that the muscle is inserted into the basi-hyal bone alone, whilst in *Balænoptera rostrata* [¶] its insertion is confined to the thyro-hyal.

Mylo-hyoid Muscle is broad and powerful. Its fibres arise from the whole length of the thyro-hyal bone, and pass forward toward the lower jaw, into which in all probability they are inserted. Unfortunately, the insertion had been cut before the specimen reached us. Its fibres are not transverse, as described by Dr Murie [**] in *Globiocephalus,* but longitudinal in direction.

Carte and Macalister [††] describe the muscles of opposite sides as blending along the middle line in *Balænoptera.* Such is not the case in Beluga.

Genio-hyoid Muscle, broad and flat, consists of a single fleshy mass occupying the middle line of the lower jaw from the symphysis to the hyoid bone. It arises from the transverse ridge on the lower surface of the basi-hyal bone by means of a flattened tendon, and passes horizontally forward toward the lower jaw. Its insertion was cut, but a comparison of the parts with Dr Murie's [‡‡] drawing of those in *Globiocephalus* leaves little doubt that in Beluga the muscle is inserted exactly as in the Bottle-nose.

Genio-glossus Muscle.—The origin of this muscle was unfortunately divided, but the relative position and direction of its fibres appeared to indicate that it represented the genial fibres of the genio-hyo-glossus of other mammals, and that consequently it arose from the posterior aspect of the symphysis of the lower jaw. The fibres pass upward, and radiating as in the human subject are inserted into the under surface of the tongue from an inch behind the tip as far back as the cartilaginous cerato-hyals.

[*] II. p. 263.
[†] I. p. 219.
[‡] II. p. 263.
[§] I. p. 219.
[||] VI. p. 480.
[¶] I. p. 219.
[**] II. p. 251.
[††] I. p. 220.
[‡‡] II. plate xxxi. fig. 11.

None of the fibres of this muscle are inserted into the hyoid bone. In this respect Beluga differs from *Globiocephalus,* in which, according to Dr MURIE,* they are inserted into the cerato-hyal and basi-hyal bones. A similar arrangement to that above described obtains, according to CARTE and MACALISTER,† in *Balænoptera rostrata.*

Stylo-glossus Muscle is narrow and riband-like, and arises from the junction of the upper and middle thirds of the stylo-hyal bone. It passes obliquely forward and downward, and is inserted into the lateral border of the tongue opposite the junction of the anterior and middle thirds of that organ. It rests upon the superficial surface of the next muscle.

In *Globiocephalus* this muscle appears to be much larger than in Beluga, and arises from the whole length of the stylo-hyal bone. The identification of this muscle with the stylo-glossus, described by CARTE and MACALISTER‡ in *Balænoptera,* is somewhat difficult. These authors describe it as lying superficial to all the other lingual muscles; whereas, in Beluga, it was concealed by the mylo-hyoid. As, however, in *Balænoptera* the last-named muscle appears to be narrower than in Beluga, it is not improbable that the difference in relative position of the stylo-glossus in the two species may be referable to this fact. Upon this hypothesis, the arrangement of the stylo-glossus is essentially the same in both.

Hyo-glossus Muscle arises from the transverse ridge on the lower surface of the basi-hyal bone under cover of the genio-hyoid muscle, as well as from the whole length of the stylo-hyal, and is inserted into the anterior two-thirds of the lateral margin of the tongue. It is placed between the stylo-glossus on the outer and the genio-glossus on its inner side.

The arrangement of this muscle seems almost identical with that described by STANNIUS § in the porpoise, and differs from that of *Globiocephalus,*|| in which the muscle consists of *two* distinct portions, one of which arises from the stylo-hyal bone. In *Balænoptera rostrata* the origin of the hyo-glossus is confined to the thyro-hyal element.

Palato-glossus Muscle measures 5 inches in breadth. The fibres pass from the palate to the side of the tongue, where they intermix with the other muscles of that organ.

This arrangement is similar to that described by Dr MURIE¶ in *Globiocephalus.*

A muscle, which is difficult to identify with any of those described by Dr MURIE** in *Globiocephalus,* or by CARTE and MACALISTER†† in *Balænoptera,* arises under cover of the hyo-glossus, from which, however, it is quite distinct and easily separable. It is narrow and riband-like, and arises from the free extremity of the thyro-hyal bone. It passes forward, crossing the outer side of

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* II. p. 252.

† I. p. 231.

‡ I. p. 231.

§ XV. p. 8.

|| II. p. 252.

¶ II. p. 254.

** II.

†† I.

the stylo-hyal element, and is inserted into the margin of the palate corresponding to the junction of the latter with the tongue.

Inter-hyoideus Muscle arises from the whole length of the anterior border of the thyro-hyal, as well as from the outer border of the basi-hyal bone. Its fibres pass horizontally forward to be inserted into the stylo-hyal bone from end to end, as well as into the outer border of the cerato-hyal cartilage. This muscle fills up the interval between the various parts of the hyoid bone, and is concealed by the hyo-glossus.

The muscle does not differ much from that described by MURIE[*] in Globiocephalus, by STANNIUS[†] in the porpoise, or by CARTE and MACALISTER[‡] in *Balænoptera*. The latter authors describe it as divisible into three portions, which they name the superficial hyo-ceratic, the deep hyo-ceratic, and the kerato-pharyngeus.

LARYNGEAL AND RESPIRATORY ORGANS.

Blow Hole.—The blow hole, situated on the top of the head 11¼ inches behind the anterior extremity of the upper jaw, and 2 inches posterior to the level of the eye, is crescentic in form, with the concavity directed forward, and is considerably narrower than the chamber into which it leads. Its posterior lip overlaps the anterior. The thick cuticle of the exterior of the animal passes just within these lips, where it gives place to the mucous membrane of the nasal chamber. The latter is of a pure white colour, and on the anterior wall of the spiracle is raised so as to form two well-marked longitudinal bands, extending from the lower or laryngeal aperture obliquely upward and outward toward the external orifice of the spiracular cavity. From each of these bands others pass more or less horizontally outward, and subside on the lateral walls of the chamber. On the spaces between these bands are numerous small apertures indicating the ducts of mucous glands. Some of these, of large size, are formed by the junction of several smaller ducts, whilst others, and these form the majority, correspond to the ducts of isolated glandules. The apertures with their associated glands are found in abundance on the anterior and lateral walls of the spiracle, but much more sparingly on its posterior wall, where they are confined to its lower part. So far as the form and position of the blow hole is concerned, Beluga agrees closely with *Grampus*, *Globiocephalus*, and *Lagenorhynchus*.

Nasal Sacs.—Situated on the anterior wall of the spiracular cavity are the openings of the nasal sacs, which are two in number, one on either side of the middle line. The upper margin of that of the right side is ¾th of an inch, and that of the left 1¼ inches from the margin of the blow hole. Each has a depth

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[*] II. p. 264.

[†] XV. p. 7.

[‡] I. p. 235.

of 1¾ inch, and measures 1 inch in diameter at its opening into the spiracle. They run obliquely forward and upward, their blind extremities lying between the integument and the wall of the skull, and contain a quantity of thick mucous-like material. Each is invested by a thick layer of muscular fibres, the exact arrangement of which could not be satisfactorily made out, owing to the separation of the soft parts from the cranium.

The number of the nasal sacs in Beluga appears to differ from that of the other whales in which these have been accurately described. According to HUNTER,[*] there are two pairs in the porpoise, whilst in *Globiocephalus*[†] and *Lagenorhynchus*[‡] Dr MURIE describes three pairs, to which in *Grampus Rissoanus*[§] a seventh must be added. The position of the nasal sacs in Beluga, projecting forward as they do from the anterior wall of the spiracle, and lying underneath the integument covering the maxillary bones, justifies us in regarding them as homologous with the premaxillary sacs described by Dr MURIE in the species above mentioned. It is, however, to be observed, that in respect of the diminutive size of these sacs, Beluga differs much from the other forms referred to. As already stated, the exact arrangement of the muscles surrounding these sacs could not be satisfactorily determined; but this is the less to be regretted in view of the very elaborate description given of them by Dr MURIE in other cetacean forms.

LARYNX.—*The Cartilages.*

Thyroid.—The alæ of the thyroid cartilage join inferiorly at a somewhat obtuse angle, forming a broad cartilaginous plate, which measures 2 inches in its antero-posterior diameter. Each ala diminishes rapidly to a depth of ½ an inch at its lateral aspect, and then as suddenly expands in a crescentic manner giving rise to the cornua of the thyroid cartilage. Of these the anterior (superior) measure ¾th of an inch in length, and are curved downwards at their extremities, whilst the posterior (inferior), measuring 1½ inch in length, are curved downwards and forwards; the latter articulate by their extremities with the postero-external surface of the cricoid cartilage close to the posterior margin of the latter. The anterior margin of the thyroid cartilage affords attachment to the thyro-hyoid ligament.

The *cricoid* cartilage, as noted by BARCLAY and NEILL in their specimen, is deficient inferiorly, an interval of ¼ of an inch separating its lateral halves. Superiorly the cartilage measures 2 inches in depth, and presents a well-marked median ridge; the anterior border is vertical in its upper part, but beyond the facets for articulation with the arytenoid cartilages, it slopes rapidly backwards and downwards. The flat articular surface for the reception of the arytenoid

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[*] XVI. p. 335. [†] II. p. 245. [‡] V. p. 146. [§] X. p. 125.

cartilage measures 1¼ inch in length; it is flat from above downwards and convex from within outwards. The posterior border of the cricoid is deeply notched in the middle line superiorly, the notch accommodating a corresponding projection of the first tracheal ring. Approaching the inferior extremities of the cartilage this border is interrupted by a deep crescentic fissure near the posterior extremity of which is the articular depression for the inferior cornua of the thyroid cartilage.

Arytenoid.—These cartilages, elongated and laterally compressed, measure 4½ inches in length. Each presents inferiorly an oblique basal surface and gradually tapers to a blunt and rounded apex, from which a spur-like process is prolonged obliquely downwards and outwards. The apices and processes of the two cartilages, when covered with mucous membrane, form the posterior thickened lip of the superior aperture of the larynx. The flattened inner surfaces of the arytenoid cartilages, though closely applied throughout their entire length, remain ununited except by fibrous membrane; there is no direct union such as MAYER* figures in *Monodon monoceros.*

The posterior border of each cartilage is straight as far down as the articular surface, below which it curves outwards, downwards, and then inwards towards the interior of the larynx, where it recurves upon itself; situated upon this border, 3½ inches below the apex, is a well-defined tubercle marked on its internal aspect by an articular surface, by means of which the arytenoid articulates with the cricoid. From the tubercle a ridge extends upwards, the lower part of which affords attachment by means of a fibrous membrane to the basal portion of the epiglottic cartilage.

The cartilages of Santorini and of Wrisberg are entirely absent.

The cartilage of the *epiglottis,* elongated equally with the arytenoids, forms about half a cylinder, broadest below, and narrowing gradually towards the apex. By its base it is attached anteriorly to the upper border of the thyroid cartilage, whilst its postero-superior angles are connected to the ridges before referred to of the arytenoid cartilages. The apex of the epiglottic cartilage is prolonged outwards and backwards on each side of the middle line, and with its mucous covering forms the anterior lip of the superior laryngeal aperture.

Ligaments of Larynx.

The *thyro-hyoid* ligament, broad, flat, and thin, occupies the interspace between the hyoid bone and the thyroid cartilage; it is attached along the entire length of their adjacent borders. A *crico-thyroid* ligament extends between the anterior border of the cricoid to the posterior border and deep

* XIX. Taf. lxxxiv.

surface of the thyroid cartilage. The posterior cornua of the thyroid are connected to the cricoid by means of strong capsular ligaments.

The form of the *crico-arytenoid* articulation is such as to admit of *rotation* of the arytenoid upon the cricoid cartilage, the effect of rotation inwards being to approximate the inferior borders of the arytenoid cartilages in the centre of the larynx, thus giving rise to the formation of two distinct channels, such as have been described by Dr MURIE in RISSO's Grampus.

The approximation of the inferior borders of the arytenoid cartilages is effected by the contraction of the *thyro-arytenoid* muscles.

Muscles of the Larynx.

Crico-arytænoidei postici are very strong; they arise from the whole of the dorsal surface of the cricoid cartilage, and also from the tips of the posterior cornua of the thyroid; the fibres pass obliquely upwards and outwards, to be inserted into the outer extremities of the tuberosities of the arytenoid cartilages.

Thyro-arytenoidei arise from the inferior mesial line of the thyroid cartilage, and are inserted into the inferior external angle of the arytenoid cartilage.

Arytenoideus.—This muscle arises between the superior surfaces of the arytenoid cartilages; it is limited to the basal third of these cartilages.

Hyo-epiglottic muscles Dr MURIE* describes as two in number. In Beluga the fibres are coalesced into a single muscular mass arising from the posterior borders of the cartilaginous cerato-hyals; the attachment to the stylo-hyals, noted by MURIE in *Globiocephalus*, does not exist in Beluga. The muscle is inserted into the posterior half of the lower surface of the epiglottic cartilage.

Crico-thyroid are strong muscles, which arise from the outer surface of the cricoid cartilage. They separate as they pass forwards, and are inserted into the posterior border of the thyroid cartilage as well as into its posterior cornua.

With respect to the action of these muscles, the arytenoid and posterior crico-arytenoid muscles separate the lower borders of the arytenoid cartilages, increasing thereby the size of the rima-glottidis, whilst the thyro-arytenoids act in an opposite manner. The hyo-epiglottideus raises the epiglottis, and the crico-thyroids approximate the cartilages between which they are placed. The presence of the last-named muscles in an animal, which, so far as we are aware, is not gifted with voice, shows that they have other and probably no less important functions than that with which they are generally credited.

A comparison of the muscles of the larynx of Beluga with those of other whales, shows a close resemblance between them and those of *Globiocephalus melas*,† and a corresponding deviation in both from the arrangement met with in *Balænoptera rostrata*.‡ There are, however, two hyo-epiglottic muscles

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* II. p. 263 (*Globiocephalus melas*).

† II. p. 263.

‡ I. pp. 237, 238.

both in *Globiocephalus melas* and in *Balænoptera rostrata,* but inasmuch as in the last named these arise from the *body* of the hyoid bone, there is a difference of origin in the two species. In Beluga, on the other hand, as previously described, the two parts are fused into a single muscle. CARTE and MACALISTER[*] consider that three aryteno-epiglottidean muscles exist in *Balænoptera rostrata,* whilst in *Balænoptera Sibbaldii,* TURNER[†] found but one. MURIE[‡] affirms his inability to distinguish them in *Globiocephalus melas;* in Beluga they are certainly absent.

Exterior of Larynx.

The free larynx projects upwards from the floor of the pharynx, and measures 3½ inches in length. Flattened from side to side, and broad at its base, it is slightly constricted in the middle, and again expands, both as regards its antero-posterior and transverse diameters, at the apex. The epiglottis is rather higher than the arytenoid cartilages, in which respect Beluga differs both from *Globiocephalus melas* and *Lagenorhynchus,* in which the reverse is the case. The epiglottic section, broader than the arytenoid, is slightly curved transversely, so that the latter cartilages are to some extent embraced by the former. The posterior segment of the apical portion of the larynx, formed by the arytenoid cartilages, presents an emarginate notch similar to that described by MURIE in *Globiocephalus melas.* The internal borders of these cartilages are in contact along the whole length of the tubular larynx. The upper opening of the latter is broad transversely, and furnished with an anterior and posterior thickened lip of mucous membrane, inclosing horn-like processes of the epiglottic and arytenoid cartilages respectively. A linear depression extends from base to apex of the lateral aspect of the organ; it indicates the borders of the epiglottidean and arytenoid cartilages, whilst another groove marks posteriorly the apposition of the arytenoid cartilages.

Interior of Larynx.

There is a complete absence of the true vocal cords; an appearance of such at first sight certainly exists, but upon more accurate examination this simulation of them is found to be due to the projection inwards of the sharp inferior borders of the arytenoid cartilages. It is, however, by no means improbable, as MECKEL[§] states, and with this view Dr MURIE[||] coincides, that these sharp edges may serve the purpose of vocal cords in the cetacea. The mucous membrane lining the posterior wall of the larynx is thrown into numerous longitudinal folds, whilst at the base of the epiglottis it is projected forwards, so as to form on each side of the middle line a pouch of size sufficient to admit

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[*] I. pp. 237, 238. [†] XVII. p. 237. [‡] II. p. 264. [§] XVIII. p. 596. [||] X. p. 129.

the point of the fore finger. This pouch is subdivided into a number of little saccules, which communicate freely with one another. It corresponds in position to the ventricles of the larynx in other mammalia, projecting outwards behind the cartilage of the epiglottis, and being invested externally by the fibres of the thyro-arytenoid muscles; inferiorly it is concealed by the thyroid cartilage. The pouches of opposite sides are separated by a well-defined mesial fold of mucous membrane. The sacculated character of the mucous membrane just described is not confined to the larynx, but extends to the upper portion of the trachea.

Probably none of the soft parts in the greater number of species of cetacea have been more completely examined, or so fully described and figured, as those constituting the laryngeal apparatus. Comparing these descriptions* and figures with those here given of the corresponding parts in Beluga, it is evident that, in respect of general form, the laryngeal cartilages of Beluga resemble closely those of the toothed whales taken collectively, whilst among these they appear to approximate in character more particularly to those of *Monodon monoceros.* MAYER* figures, however, in the latter species, a direct union superiorly of the arytenoid cartilages, which is not found in Beluga.

In the toothed whales both the epiglottidean and arytenoid cartilages are prolonged to an almost equal extent (this condition being more especially noticeable in the females of different species); they are, moreover, united together by fibrous tissue throughout their whole length, and terminate superiorly in rounded and expanded apices, so that a free tubular larynx with a glottis bounded by thickened lips results.

To these sectional characteristics Beluga entirely conforms, and in this respect differs very strikingly from the group of whalebone whales. The latter are distinguished by very characteristic laryngeal features, which, nevertheless, are distinctly of the cetacean type. A free conical larynx exists, much shorter, however, than that of the toothed whales, and with correspondingly short epiglottidean and arytenoid cartilages, which do not possess expanded apices, and which, moreover, are not united together in the whole of their extent. Such union as does exist is limited to the basal portions of the cartilages, whilst their upper parts remain free, and hence "the respiratory canals appear undoubtedly to be less completely closed before than in the toothed whales."†

ESCHRICHT and REINHARDT‡ are of opinion "that the most essential peculiarity in the larynx of whalebone whales, as compared with that of the toothed whales, consists in its allowing the mucous membrane of the respiratory canals, by means of an opening on its ventral surface, to appear in the form of a sac with

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* XIX. Taf. lxxxiv. fig. 104.

† "Cetacea," p. 102, Ray Soc., 1866.

‡ XX. p. 101.

an exterior covering of a strong layer of muscles." That the presence of a ventral air-sac in connection with the larynx of whalebone whales is of constant occurrence may be correct; certainly in them it attains its greatest development. But it is by no means so clear that it can be regarded as a specific character of the whalebone group. On the contrary, the existence of a small but analogous sac which, as Dr MURIE [*] points out, "fills in great part the angle of junction between the enlarged epiglottis and the thyroid cartilage, but does not reach the posterior border of the latter," in RISSO'S Grampus, shows that the arrangement in question is not confined to the whalebone whales. In Beluga, as we have seen, the arrangement is similar to that described in RISSO'S Grampus, and Dr MURIE'S[†] assertion that the above apparent distinction between the whalebone and toothed whales is one rather of degree than of kind, is thereby corroborated. The truth of this observation is rendered still more apparent by a comparison of Dr MURIE'S figure of the sac in RISSO'S Grampus with that of the same structure in the *Balænoptera Sibbaldii* described by Professor TURNER. [‡]

Be this as it may, the great difference in the shape and connections of the laryngeal *cartilages* in whalebone whales, as contrasted with those of the toothed species, is sufficient to differentiate the two groups.

CUVIER [§] affirms the absence both of ventricles and of vocal cords in the cetacean larynx, and, so far as the latter are concerned, we agree with his observations, notwithstanding Dr MURIE'S [||] assertion that rudimentary vocal cords are present in the larynx of *Grampus*. At least in Beluga, with the exception of the free margins of the arytenoid cartilages, we could not distinguish any structure which could functionally represent these cords. With regard to the laryngeal ventricles, on the other hand, we must differ from the distinguished French anatomist. We have already directed attention to the presence in the larynx of Beluga of two pouches which correspond in position to the ventricles of other mammals, and that they ought really to be regarded as homologous with such seems proved by the following considerations :—*Firstly*, That their relation to the thyroid cartilage and to the thyro-arytenoid muscles is the same in both ; *secondly*, That in some ruminants, *e.g.*, *Saiga tartarica*,[¶] as pointed out by Dr MURIE, the arrangement of the ventricles is similar to that described above in Beluga, these ventricles forming a single pouch which projects downward and backward into the hollow of the thyroid cartilage. In the ruminants referred to, moreover, as in those whales which possess a laryngeal sac, there is no trace of any other cavity which can correspond to the laryngeal ventricles. *Thirdly*, That this sac in Beluga is essentially a bilateral structure is shown by the presence of the anterior mesial fold in its interior, which, were it de-

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[*] X. p. 127.

[†] X. p. 127.

[‡] XVII. plate viii. fig. 36.

[§] XXXI. vol. iv. p. 54.

[||] X. p. 130.

[¶] XXXIX. p. 491.

veloped to a greater extent, would completely separate the two halves from each other, and cause them to communicate by distinct apertures with the interior of the larynx in precisely the same manner as the ventricles do in the majority of mammals.

We must either accept this view with regard to the homologies of the laryngeal sacs of the toothed whales, or regard them as structures altogether confined to the cetacea, and having no representatives in other mammals. The latter alternative we are by no means inclined to accept. Nor will it do to regard the sacs as homologous with the subepiglottic ventricle of the horse and ass, or with the large air space found in a corresponding position in certain of the quadrumana (Mandrill*), for the reason that the latter have no relation to the thyro-arytenoid muscles, which, in the animals referred to, maintain their normal relation to the ventricles of Morgagni, these ventricles occupying their usual position in the laryngeal cavity. A similar argument might be advanced with reference to the air sac which in Ateles projects outward between the thyroid and cricoid cartilages, and which, therefore, at first sight, presents an arrangement not unlike that of the large laryngeal sac of the whalebone whales. We are, therefore, by a process of exclusion, compelled to regard the laryngeal pouches of the toothed whales as homologous with the ventricles of Morgagni. Now, if we imagine these pouches (which communicate freely with one another by reason of the deficiency of the mesial septum) of the *toothed* whales to be inflated so that the single sac would project altogether beyond the space bounded by the laryngeal cartilages, by means of the interval between the cricoid and thyroid cartilages, we should have an arrangement essentially similar to that of the laryngeal sac in the *whalebone* whales. In connection with this difference in size and relations of the laryngeal sac in the whalebone, as contrasted with the toothed whales, it is interesting to observe the adaptive modification of the laryngeal cartilages in the latter. The cricoid cartilage in these is deficient inferiorly, and the neck or constricted portion of the enormous laryngeal sac is supported by the posterior cornua of the arytenoid cartilages; whereas in the toothed whales the cricoid is either complete or almost complete inferiorly, and the arytenoid cartilages are destitute of the peculiar posterior cornua which in the whalebone whales appear to supply the place of the deficient cricoid. Moreover, in the whalebone group the inferior angle of the thyroid cartilage is reduced to a mere tongue-like process, so that a large interval exists between its posterior extremity and the first complete tracheal ring, which interval permits of the passage outwards of the laryngeal pouch. In the toothed whales, on the contrary, the thyroid cartilage is not aborted in this manner, and the laryngeal pouch does not extend beyond the cavity of the

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* XXXII. plate vii. figs. 1, 2, and 3.

larynx. Lastly, the arrangement of the muscular fibres which lie in relation to the laryngeal pouch is essentially similar in the toothed and in the whalebone whales. Dr MURIE,* in his article on RISSO's Grampus, arrives at the conclusion that these fibres belong to the thyro-arytenoid muscles, and the description given above of these muscles in Beluga leaves no doubt of the accuracy of this opinion. The same author * observes that the thyro-arytenoid muscles in *Grampus* "evidently correspond to those transversely-striped whorled muscular fascicles which surround or form the exterior coat of the so-called air bag or laryngeal sac both in the Right, the Pike whale, and the Razor-back." A reference to Professor TURNER's † description of these fibres in *Balænoptera Sibbaldii* and to that of CARTE and MACALISTER ‡ of the same in *Balænoptera rostrata,* shows that in the whalebone whales the muscles of each side surrounding the laryngeal pouch are attached by one extremity to the angle of the thyroid, and by the other to the body of the arytenoid and free border of the cricoid cartilage. In other words, we have in them a muscle which corresponds exactly to the thyro-arytenoid of other mammals, including the toothed whales. The cricoid attachment of the muscle appears to militate against this interpretation, but as neither TURNER nor CARTE and MACALISTER refer to a lateral crico-arytenoid, it seems by no means improbable that these cricoidal fibres may represent the crico-arytenoideus-lateralis.

Now, if we imagine the laryngeal sac above described in Beluga to be expanded so as to project beyond the larynx opposite the interval between the cricoid and thyroid cartilages, accompanied by an adaptive alteration in the form of these cartilages, we should have the pouch invested by an almost complete layer of circular muscular fibres similar to that described by SANDIFORT,§ ESCHRICHT and REINHARDT,‖ TURNER,¶ and CARTE and MACALISTER‡ in different species of whalebone whales.

Taking then into consideration—1*st,* The essentially bilateral character of the laryngeal sac of the toothed whales ; 2*d,* The relation in which it stands to the thyroid cartilage and to the thyro-arytenoid muscles,—we come to the conclusion that the relatively small pouches of the toothed whales are homologous with the ventricles of Morgagni of other mammals, and that the enormous laryngeal sac of the whalebone whales must be equally regarded as their morphological equivalent.

The comparative shortness and non-union apically of the epiglottidean and arytenoid cartilages has been already referred to as characteristic of the whalebone whales. A still more interesting modification of the arytenoid cartilages in that group appears to be consequent upon the condition of the

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* X. p. 129.

† XVII. p. 238.

‡ I. p. 238.

§ XXIV. p. 246.

‖ XX. p. 101.

¶ XVII. p. 238.

cricoid cartilage, which, less differentiated than usual from the succeeding tracheal rings to which it is united, is like them deficient ventrally. The interspace thus left is occupied by a membrane continuous with that which fills up the interval left by reason of a similar incompleteness of the anterior tracheal rings. The arytenoid cartilages are prolonged backwards and downwards to form posterior horns, which, reaching the lower part of the larynx, turn inwards and approach each other, leaving but a slight interval between their extremities. This interval in the recent state is occupied by a ligamentous band which connects the two posterior horns. Thus a distinct arch is formed, which, taking the place of the deficient ventral portion of the cricoid, apparently compensates for its loss.

So far as we can ascertain, the cricoid is never so incomplete ventrally in the toothed whales; on the contrary, it usually forms a distinct ring. In some species, however, *e.g.*, *Beluga*, *Phocœna communis*, the ring is not quite perfect, although almost so. In no species of toothed whale yet described are the arytenoids prolonged into posterior cornua, as in the whalebone whales.

To summarise, in respect of the larynx Beluga conforms to the characteristics of the toothed whales in general; at the same time, possessing as it does a small laryngeal sac and a cricoid cartilage ventrally incomplete, it manifests a tendency toward the possession of that form of larynx met with in the group of whalebone whales.

Trachea.—The windpipe, from the posterior border of the cricoid cartilage to the point of bifurcation into its terminal bronchi, measures 6 inches in length. Somewhat flattened from above downwards, its greatest diameter is transverse, and measures 2 inches. Of the cartilaginous rings forming part of its wall there are fifteen, seven of which are situated in front of an accessory bronchus to be presently described. The rings, as a rule, are complete, and entirely surround the trachea; there is consequently an absence of the so-called membranous portion of the trachea usually met with in other mammals. The three anterior rings, however, form an exception to the general rule, their ventral segments being deficient; the corresponding portion of the tracheal wall just behind the cricoid cartilage is therefore entirely membranous.

Bronchi.—The bronchi are three in number, of which two correspond to those commonly resulting from the bifurcation of the trachea; whilst the third (*azygos*) is given off from the trachea about 2¼ inches in front of the bifurcation. This accessory bronchus passes to the right lung, and enters its inner surface 4 inches in front of the entrance of the principal or terminal bronchus. It is the smallest of the bronchi, measuring when flattened only ¾ of an inch in breadth. Of the principal bronchi, the right measures 4 inches in length from the tracheal bifurcation to the point at which the first intra-pulmonic air-tube is given off; whilst the left, between the corresponding points, measures but

$2\frac{1}{2}$ inches. Each is flattened from above downwards, and measures $1\frac{1}{4}$ inch in breadth. They enter the mediastinal surfaces of the respective lungs about one-third nearer the apex than the base, and somewhat nearer the dorsal than the ventral margin of the latter. As in the trachea, so in the bronchi, the cartilaginous rings are complete. The mucous membrane lining the air-passages is thrown into longitudinal folds, as in the majority of the larger mammalia.

Lungs.—Each lung measures 18 inches in length from base to apex, and presents three uniformly smooth surfaces. Neither of the lungs shows the slightest trace of any tendency to lobar subdivision. The surfaces of the lung are parietal, mediastinal, and diaphragmatic—names which sufficiently indicate their relative positions and connections with surrounding parts. A thick and rounded superior border, as well as a thin and sharp inferior margin, are noticeable. Each principal bronchus enters the inner or mediastinal surface of the corresponding lung, as previously described; the single or accessory bronchus reaches the inner surface of the right lung, and enters its substance midway between the point of entrance of the principal bronchus and the apex. Upon the left side the principal bronchus, after entering the lung, furnishes a large offset, which runs forward towards the apex, whilst the main tube continues backward to the base of the organ, lying close to its mediastinal surface and superior border. From these primary tubes secondary branches pass off in all directions, except towards the inner surface of the lung. The subdivision of the bronchial tubes within the lung does not take place dichotomously, as in *Balænoptera Sibbaldii,*[*] but is quite irregular. The cartilaginous elements of the intra-pulmonic bronchi are in the form of complete rings, even where the latter do not exceed $\frac{1}{12}$th of an inch in diameter. This recalls to mind the similar arrangement met with in the lungs of the Dugong.[†] Water injected into the main bronchus of the right lung does not distend the apex of this organ, which, indeed, can only be effected when the fluid is introduced through the medium of the accessory bronchus. From this circumstance, it appears that in Beluga the communication between the principal and accessory bronchi of the right lung is not so free as HUNTER[‡] affirms it to be in other species. This relation, however, according to JACKSON,[§] is not so common as HUNTER imagined.

The pleural membrane covering the lung is thick and leathery, but we could not distinguish any subjacent elastic coat such as is found in many of the larger mammals.

Lying in close relation to the inferior border of each lung, and near the junction of its diaphragmatic and inner surfaces, is a large lymphatic gland,

[*] XVII. p. 235. [†] XXI. vol. iii. p. 580. [‡] XVI. p. 334. [§] IV. 149.

similar to that described by Dr Murie[*] as occupying a corresponding position in *Globiocephalus melas.* On the right side the gland measures 5 inches in length, and lies superficial to a second gland of equal size, which rests against the inner surface of the lung, and occupies the space between the ventral or inferior border and the hilum of the organ. On the left side there is but a single lymphatic gland, which corresponds in position to the most superficial of the two glands noted on the right side; it is, however, not so large by one-half. Numerous vessels radiate outwards from these glands as from a centre, and run upon the outer surfaces of the lung. Their exact nature could not be determined, but in all probability both sanguiferous and lymphatic vessels were present, as described by Dr Murie[†] in *Globiocephalus melas.* The lymphatic glands are invested superficially by pleural membrane prolonged from the surface of the lung. The glands of opposite sides are almost in contact, the interspace being occupied by pleural membrane, an arrangement which gives rise to the bridge-like appearance figured by Dr Murie.[†]

Wyman[‡] noted in his Beluga a free communication between the different parts of each lung. This, as we have pointed out, did not exist in our specimen. Barclay and Neill[§] assert the osseous character of the intra-pulmonic bronchial rings. Probably, however, they were cartilaginous and not bony. With these exceptions—the pulmonary organs of Beluga, so far as they are described by the above-named observers, presented characters identical with those we have noted in the text. Both as regards their shape and unilobular character, the lungs of Beluga agree with those of almost every other cetacean.

Among the toothed whales, *Globiocephalus melas*[||] and Risso's Grampus[¶] are described as possessing a more or less well-defined antero-inferior pulmonic lobe. Burmeister[**] notes two unequal parts in the right lung of *Epiodon cryptodon* (Gray); whilst Dr Williams[††] asserts the existence in the *Chinese Globiceps* of two lobes in each lung. This lobulated condition has not, so far as we are aware, been described in any other toothed whale, nor in any member of the whalebone group. The large glandular bodies situated at the "post-ventral" margins of the lungs in Beluga appear to have been first fully described by Hunter.[‡‡] Dr Murie notes their presence in Risso's Grampus[¶] and in *Globiocephalus melas;*[†] they exist, moreover, in *Delphinus tursio;*[‡‡] also in Gulliver's,[§§] Williams',[||||] and Jackson's[¶¶] whales.[***]

In respect of their arrangement in the various species of Cetacea, the trachea and bronchi present but few variations from that described above in Beluga. So constant, indeed, is this arrangement of the respiratory channels in the different

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[*] II. 265.
[†] II. p. 266.
[‡] III. p. 610.
[§] VIII. p. 388.
[||] II. p. 265.
[¶] X. p. 131.
[**] XLI. p. 96.
[††] XIV. p. 412.
[‡‡] XXII. p. 107.
[§§] XXIII. p. 63.
[||||] XIV. p. 412.
[¶¶] IV. p. 164.
[***] The specimens examined by both Gulliver and Jackson belonged to the genus *Globiocephalus.*

members of the group, that we find certain observers* affirming that the only exception is formed by the Greenland Right whale (*Balæna mysticetus*), in which, as Sandifort† first pointed out, the observation being subsequently corroborated by Eschricht and Reinhardt,‡ the trachea presents the peculiarity of "being only bifurcated into two bronchi, that branch, which in other cetaceans (and several land mammals) issues from the trachea before its bifurcation into those two bronchi, not being found here." There are, however, among the cetacea two other exceptions to what, in respect of the subdivisions of the trachea, may be called the usual arrangement. We refer to *Pontoporia Blainvillii*, in which Dr H. Burmeister§ describes and figures a trachea which, previous to its bifurcation, gives off *two* accessory bronchi which pass, one to the right and the other to the left lung. A similar arangement has been described in *Monodon monoceros.*|| Another interesting but less remarkable deviation from the usual arrangement was found by Carte and Macalister¶ in *Balænoptera rostrata.* Here the three-fold bronchial arrangement exists, but the accessory bronchus, instead of coming from the trachea prior to its bifurcation, is given off further back than usual, and thus becomes an offset of the right principal bronchus. *Balænoptera* thus presents an arrangement intermediate between that of the exceptional Greenland Right whale and that met with in the majority of the cetacea. Beluga, then, in respect of the respiratory organs, agrees with the greater number of cetaceans, and differs only in the relatively greater length of the trachea. Irregularity of the posterior tracheal rings, and incompleteness of those situated next the larynx, are met with in most cetaceans. The annular form of the intra-pulmonic bronchial cartilages is likewise common throughout the order.

Circulatory Organs.

Heart.—The heart is broad, and, as usual in cetaceans, is somewhat flattened from above downwards. Its length from base to apex corresponds to its basal breadth, the measurement in each case being 6 inches. The auricles are capacious, and possess large appendages. Internally, the walls of the auricles are for the most part quite smooth; each appendix, on the contrary, is provided with numerous well-developed trabeculæ carneæ. These consist of fleshy bands, which, attached to the walls of the heart by their extremities, are free in the middle. They are not arranged in the regular, pectinate manner so common in the mammalian heart, but cross one another in all directions—those of the left side being more regularly disposed than are those of the right. The cavity of the right

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[*] II. p. 265; XVII. p. 236.

[†] XXIV. p. 245.

[‡] XX. p. 103.

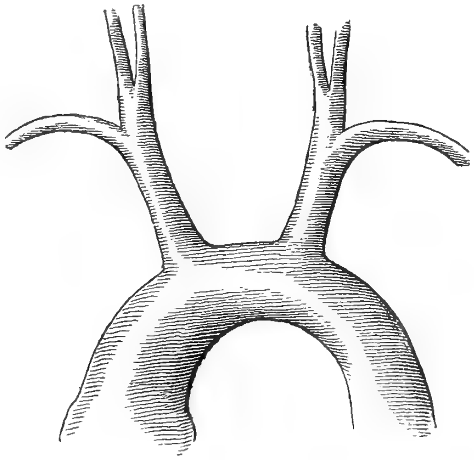
[§] XXV. p. 484.

[||] XXVI. p. 139.

[¶] I. p. 243.

auricle presents but two caval openings. Whether these were provided with valves or the reverse could not be ascertained, as the heart had unfortunately been damaged before coming into our possession. Instead of a single opening of the coronary sinus we distinguish two. They are placed close together in the usual position of that sinus, and are the orifices of two large veins, the trunks of which are situated in the right auriculo-ventricular and right ventricular grooves respectively. Neither of these openings presents the slightest trace of a Thebesian or coronary valve. It thus appears that in our specimen a coronary sinus, properly so called, does not exist; but whether this is to be regarded as the normal arrangement of the cardiac veins in *Beluga catodon,* or merely as an individual peculiarity of exceptional character, can only be decided by more extended investigation. The cavity of the right ventricle presents no feature worthy of note, except the large size of the columnæ carneæ and musculi papillares. The right auriculo-ventricular valve consists of three cusps, which are arranged in the usual manner. It presents no trace of the remarkable perforation observed by MURIE[*] in *Globiocephalus melas.* In the left ventricle the papillary muscles and fleshy columns are of enormous size, the latter inter-crossing in all directions. The valves do not present any deviation from the arrangement usually found in the mammalian heart.

The Aorta arches over the root of the left lung. In addition to the coronary arteries for the supply of the heart, the arch of the aorta furnishes two innominate trunks, these being derived from its transverse portion. Each innominate artery measures 2 inches, and terminates by dividing into a common carotid for the supply of the head and neck, and a subclavian which is distributed to the flipper. The common carotid runs a short course of about half an inch, and then divides into two trunks of equal size, both of which run forward towards the head. Doubtless these represent the external and internal carotids. Their exact distribution could not be traced, owing to the state of the parts. This was also the case with several large branches which, springing from the subclavian, passed to the parts about the scapula.



Beluga.—Semi-diagramatic view of the aortic arch and its branches, reduced.

With reference to such points in the anatomy of the circulatory system as are noted in previously described Belugæ, we find that the account given by WYMAN,[†] of the heart and aorta with its branches, agrees in the main with

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[*] II. p. 266.

[†] III. p. 608.

ours. This observer, however, notes a slightly notched condition of the cardiac apex which did not exist in our specimen. He makes no reference to the coronary sinus or to the openings of the cardiac veins, on which points Barclay and Neill[*] are equally silent. The latter, indeed, do not appear to have examined the heart specially, and give no account whatever of the aorta and its branches.

Cetaceans in general agree with Beluga in possessing a heart characterised by its flattened character and capacious auricles. In no species is the substitution of *two* venous orifices in the place of a coronary sinus described; it may therefore in all probability be regarded as exceptional in Beluga. Dr Jackson[†] affirms the existence of a single coronary opening, unprovided with any valve, in the spermaceti whale; Turner[‡] notes the presence of a coronary sinus, and the absence of any Thebesian valve, in the fœtus of *Balænoptera Sibbaldii;* and Burmeister[§] speaks of the single orifice of the nutritive vein in *Ziphiorrhynchus cryptodon* (*Epiodon cryptodon,* Gray).

But, though no remarkable differences are to be found in the hearts of the different cetaceans, quite the reverse holds good with respect to the aorta and its branches, the differences in arrangement of these vessels being manifold. In most cetaceans the aorta is large at its commencement, but suddenly contracts in the arch—a condition first noticed by Jackson[‖] in *Phocæna globiceps.* The number of branches (exclusive of the coronary arteries) given off from the arch varies, as does also the arrangement of these. In Beluga two innominates, each dividing into a common carotid and a subclavian, are the only branches. Amongst the toothed whales two innominate trunks seem to be the rule; but in most cases an additional branch, such as a deep intercostal or superior thoracic branch, is also to be found springing from the arch. In *Delphinus phocæna*[¶] the left posterior thoracic occasionally springs from the arch; usually, however, the latter agrees with that of Beluga in simply giving off two innominates. According to Cuvier and Meckel, in the porpoise each of these divides into a common carotid, subclavian, and vertebral, whilst Stannius,[**] Rathke,[**] Barkow,[**] and Turner[**] maintain that no common carotid exists, and that the external and internal carotid arteries arise separately from the innominate. In *Globiocephalus Svineval,* Turner[¶] describes and figures two innominates and a left posterior thoracic as springing from the aortic arch, the external and internal carotids, together with the subclavian of each side arising directly from the trunk of the innominate artery. A similar arrangement is noted by Murie[††] in Risso's Grampus (*Grampus Rissoanus*).

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[*] VIII. p. 380.

[†] IV. p. 147.

[‡] XVII. p. 227.

[§] XLI. p. 96.

[‖] IV. p. 164.

[¶] IX. p. 66.

[**] Quoted by Turner, IX. p. 66.

[††] X. p. 133.

The whalebone whales, in the matter of the aortic branches, resemble more closely of the arrangement met with in man. CARTE and MACALISTER,* TURNER,† KNOX,‡ ESCHRICHT,§ and MALM|| all affirm the existence of a right innominate (which divides simply into a common carotid and a subclavian), as well as a left carotid and left subclavian, the three branches arising directly from the arch of the aorta.

Contrasting Beluga with the two sections, it is seen to agree with the toothed whales in so far as regards the existence of two innominate trunks, but to differ from them in the absence of additional branches from the arch, and in the more regular distribution of the innominates by means of a subclavian and a common carotid—the latter apparently not existing in other toothed whales, with the doubtful exception of *Delphinus phocæna.* From the whalebone whales it only differs in the fact that the common carotid and subclavian arteries on the left side do not come directly from the aorta, but from a left innominate trunk. Beluga, therefore, presents an arrangement which may be regarded as intermediate between the two sections.

BRAIN AND ORGANS OF SENSE.

Brain.—This organ we did not examine, as the state of the parts precluded the possibility of obtaining an accurate and reliable description of its structure. Fortunately, we possess a means of supplementing this deficiency in our own observations, in an excellent paper with accompanying drawings, by Dr HERBERT MAJOR,¶ published in the last number of the "Journal of Anatomy and Physiology." In it, in addition to the results of an elaborate investigation into its microscopic structure, with which we are not here immediately concerned, will be found the following description, by Professor TURNER, of the cerebral convolutions in Beluga, drawn up from an examination of a photograph of the left hemisphere:—

"A well-marked Sylvian fissure was present on the outer surface of the hemisphere. The convolutions were arranged around this fissure in four successive tiers, separated from each other by three well-defined fissures which extended generally in the antero-posterior direction. On the inner surface of the hemisphere the convolutions presented considerable complexity, but they were obviously arranged in relation to the direction of the corpus callosum, and extended in the antero-posterior direction from the frontal end of the cerebrum backwards and downwards. There was evidence of a division of the convoluted mass into three successive tiers by intermediate furrows extending antero-posteriorly above the corpus callosum and the convolutions of the middle tier

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* I. p. 245.

† XVII. p. 229.

‡ XXVII.

§ XXVIII. p. 104.

|| XXIX.

¶ XXX. p. 128.

were in greater mass than those of either the upper or the lower tier. The convolutions of the two lower tiers reached the temporo-sphenoidal part of the hemisphere, while those of the upper tier did not extend so far down, but stopped at the occipital end of the cerebrum. The convolutionary arrangement, as above indicated, presented the closest similarity in both hemispheres."

Eye.—The eye is small, and is situated 9 inches behind the extremity of the muzzle.

Ear.—According to WYMAN,[*] the external auditory opening is "of a size sufficient to admit a bristle, and surrounded by a very slight elevation of the integument." According to BARCLAY,[†] no trace of an auditory opening is distinguishable.

URINARY ORGANS.

Kidney and Ureter.—The kidney has the form of an elongated flattened cake, measuring 9 inches in length, with an average breadth of 3¼ inches. Its anterior extremity is rounded, whilst its posterior extremity is more pointed in form. The organ is enclosed in a stout fibrous capsule, upon opening which the kidney is seen to be composed of a number of distinct and easily separable lobules. Each of these has an average diameter of one-fourth of an inch, and is polygonal in form, so that the adjacent lobules, when *in situ,* are accurately applied to one another, only a delicate prolongation of the external capsule intervening, and forming a complete investment to each of them. The lobules are over 400 in number. Each in itself forms a complete renal organ, and is provided with a separate duct. The ducts, uniting with one another, finally give rise to the ureter. The renal blood-vessels enter the kidney close to its anterior extremity, whilst the ureter, formed as above described, and presenting no trace of a dilated portion or pelvis, passes off from the posterior extremity of the organ. The ureter is wide, and its walls are thin. It enters the bladder a short distance behind the neck, after traversing obliquely the coats of the viscus.

Bladder is small in size, and regularly pyriform. It measures 3 inches from base to apex. Its superior surface is entirely covered by peritoneum.

Urethra measures 3 inches in length, and is closely attached to the lower wall of the vagina. It opens into the vulva immediately behind the clitoris.

The urinary organs of Beluga differ but little from those of other cetacea. As observed by GULLIVER,[‡] TURNER,[§] and MURIE[||] in *Globiocephalus,* and by CARTE and MACALISTER[¶] in *Balænoptera rostrata,* the renal vessels enter the kidney close to the anterior, whilst the ureter passes off from the posterior extremity of

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[*] III. p. 610.

[†] VIII. p. 394.

[‡] XXIII. p. 65.

[§] IX. p. 75.

[||] II. p. 284.

[¶] I. p. 251.

the organ. The same arrangement holds good in Beluga. In *Lagenorhynchus* [*] Dr MURIE noticed the coalescence of several of the renal lobules in contra-distinction to the isolated character of these in *Globiceps* and other species. But such was not the case in Beluga. As a rule, the urinary bladder seems to be of small size in the cetacea, the only exception being that of *Zyphiorrynchus,* in which, according to BURMEISTER,[†] it is of *large* size. In respect of the size and form of this viscus, Beluga agrees with the majority of the cetacea.

FEMALE GENERATIVE ORGANS.

Vulva.—The vulva is represented by an elliptical fissure 5 inches in length, the posterior extremity of which is situated three-fourths of an inch in front of the anus. The integument surrounding the former is smooth and elevated, so as to form two well-marked lateral pads representing the labia majora. Lying in the anterior commissure of the vulva, and to some extent concealed by the labia majora, are two well-defined folds of mucous membrane—the labia minora. Each measures 1 inch in length, and together they enclose an elliptical space in which lies the clitoris. The nymphæ are quite continuous with one another *behind* the clitoris, and form a prepuce for that body; whilst in *front* of it they are lost in the anterior commissure of the vulva, where they become continuous with the inner surfaces of the labia majora. The body of the clitoris, measuring one-fourth of an inch in length, is conical in form, and somewhat flattened from side to side. The nymphæ unite with it and with each other along its posterior border.

The external genital organs do not appear to vary much in female cetaceans. Alike in the toothed and in the whalebone whales, there is a well-developed clitoris, together with labia majora and minora. With regard to the latter, Dr MURIE [‡] states that in *Globiocephalus* they form "two prominent folds of mucous membrane, each an inch in length, which lie within the anterior pudendal commissure, and *slightly converge as they pass backwards.*" This arrangement appears to indicate an approach to that described above in Beluga, in which the labia minora unite with one another behind the clitoris to form the prepuce. In *Balænoptera Sibbaldii,* Professor TURNER [§] observed that the labia minora "passed backward external to the meatus urinarius;" whereas in Beluga they become continuous with one another *in front* of that orifice.

Vagina.—The vagina measures 8 inches in length and 2½ in breadth when flattened. Its superior or dorsal surface is invested by peritoneum to within two inches of its posterior extremity, at which spot the serous membrane is reflected to the rectum. The inferior or ventral surface is also covered by peritoneum as far back as opposite the vesical extremities of the ureters, whence it is

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[*] V. p. 149.

[†] XLI. p. 97.

[‡] II. p. 285.

[§] XVII. p. 201.

reflected to the superior wall of the bladder. The diameter of the vagina is uniform except at its uterine extremity, where it suddenly contracts to a breadth of an inch and a quarter, this contraction indicating externally the position of the os uteri in the interior. On slitting open the tube its mucous membrane is seen to be thick and of a milk-white colour, and to present different characters at different parts of the canal. Corresponding to its posterior fourth the lining membrane of the vagina is thrown into a number of longitudinally arranged colossal fleshy columns, which, in the second fourth of the canal are replaced by a series of very minute folds lying parallel to one another and to the long axis of the tube. In the anterior half of the vagina these rugæ are, as it were, doubled upon themselves at regular intervals, so giving rise to a series of circular valve-like folds, the free margins of which present a fringed or puckered appearance, and project into the lumen of the canal. Of these circular folds we counted eight. The most anterior of them is of larger size than the others, and closely surrounds the os uteri.

The condition of the vaginal mucous membrane above described appears to be constant in cetaceans. The number of transverse folds, however, varies in different species. HUNTER describes two in the porpoise, and states that in some species there are as many as nine.* Dr MURIE † counted four in *Globiocephalus.* Both Dr MURIE ‡ and Professor TURNER § remark upon the similarity in appearance of these folds in *Globiocephalus* to the margins of the os uteri. The same observation holds good of Beluga.

Uterus and Fallopian Tubes.—The uterus lies between the widely expanded peritoneal folds, forming the broad ligament. The corpus uteri measures only 2 inches in length, its junction with the vagina being clearly indicated externally by the constriction before referred to. The os uteri, of very small size, is surrounded by the most anterior of the valve-like vaginal folds already referred to. Each of the anterior angles of the uterus is prolonged into the corresponding uterine cornu. The latter, 6 inches in length and $\frac{3}{4}$ of an inch in breadth, is flattened from above downward, and diminishing in size at the extremity to the thickness of a crow quill, becomes continuous with the Fallopian tube. This tube measures 3 inches in length, and continues of uniform diameter as far as its extremity, where it suddenly expands into a wide peritoneal infundibulum, altogether destitute of fimbriæ. Connected with each cornu uteri, and lying between the layers of the broad ligament, is a number of well-marked fibrous cords, which apparently represent the partially obliterated organ of Rosenmüller. The mucous membrane of the corpus uteri, as well as of the cornua, is thrown into longitudinal folds, which diminish in size toward the abdominal opening of the Fallopian tube. A large number of blood-vessels

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* XVI. p. 348.

† II. see plate xxxviii. fig. 74.

‡ II. 285.

§ IX. p. 76.

pass forward between the edges of the broad ligament, to be distributed to the uterine horns.

In certain cetaceans there appears to be no separation between the uterus and vagina, the difficulty of deciding where the one ends and the other begins being attributable to the absence of an os uteri. This condition has been noticed by JACKSON* in the sperm whale, and by HUNTER† in *Hyperoodon.* The latter author says‡—"From the last projecting part" (*i.e.*, the highest of the transverse vaginal folds above described) "the passage is continued up to the opening of the two horns, and the inner surface of this last part is thrown into longitudinal rugæ, which are continued into the horns. Whether this last part is to be reckoned common uterus or vagina, and that the last valvular part is to be considered as os tincæ, I do not know; but from its having the longitudinal rugæ, I am inclined to think it is uterus, this structure appearing to be intended for distinction." There is no doubt of the correctness of HUNTER's conclusions when the uterus of either *Globiocephalus* or of Beluga, in both of which there is a clearly defined os uteri, is examined. At the same time that a transverse fold similar to those found in the vagina *may* occur in the body of the uterus itself, is proved by Dr MURIE's§ observation on *Globiocephalus,* and justifies the difficulty which even JOHN HUNTER experienced in fixing the limit between the two organs. The corpus uteri, when it can be clearly defined, is uniformly of small size in the cetacea.

The Fallopian tubes in Beluga resemble closely those of *Hyperoodon.* HUNTER‖ describes them in the latter as being remarkably small close to the uterus, but expanding gradually to their abdominal extremities, so that they resemble a French horn,—a description, the accuracy of which is shown by the accompanying drawing of the female organs in Beluga. Dr MURIE¶ refers to the presence of fimbriæ at the extremity of the Fallopian tube in *Globiocephalus.* Beluga is destitute of such.

Ovary.—Of large size, and of an elongated oval form, the ovary measures 2½ inches in length and ¾ of an inch in breadth. It presents the appearance of being rolled upon itself round its transverse axis, the convex surface of the organ being directed upward and lying in contact with the superior layer of the ligamentum latum uteri. Its surface is thrown into five or six parallel longitudinal ridges which extend from end to end of the organ. A number of opaque fibrous cords radiate outward from the outer extremity of the ovary, lying between the layers of the broad ligament of the uterus. The exact nature of these is open to discussion. In addition to them, another series of obliterated tubules, before referred to, pass off from the anterior border of the organ, and

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* IV. p. 145.

† XXII. p. 112.

‡ XVI. p. 348.

§ II. p. 285.

‖ XVI. p. 349.

¶ II. p. 285.

are lost in the neighbourhood of the Fallopian tube. They are doubtless to be considered as representing the parovarium, or organ of Rosenmüller. No trace of Gaertner's canals could be made out. The surface of the ovary presented no appearance of either Graafian follicles or of ova.

The ovary of Beluga differs from that of *Globiocephalus* in its more elongated form, and in the presence of the superficial longitudinal ridges above referred to. This character, so far as we can ascertain, has not been noticed in any other cetacean with the exception of the sperm whale, in which, according to Dr JACKSON,[*] the surface is "somewhat fissured." Dr MURIE[†] describes the ovary in *Globiocephalus* as being arched over by a pavilion derived from the broad ligament of the uterus and the Fallopian tube. We could not distinguish this arrangement in Beluga.

Clitoris is formed by the junction of two crura, one of which is attached to each of the rudimentary pelvic bones. The latter are small, cylindrical in form, and measure 2½ inches in length and ⅛ of an inch in transverse section. They are placed one on either side of the vagina at a depth of 3 inches from the surface, the anterior extremity of each in the natural position of the animal being directed obliquely downward and forward, whilst the posterior extremity looks upward and backward. The crus clitoridis, attached to the posterior half of the corresponding pelvic bone, is of large size, and covered by the fibres of a well-developed erector clitoridis. It unites with its fellow to form the body of the clitoris already described. In addition to the erector clitoridis, there were several other muscles attached to the pelvic bone which, so far as the state of the parts enabled us to observe, appeared closely to resemble those described by Dr MURIE[‡] in *Globiocephalus.* We may therefore refer to the excellent monograph of that author, with its accompanying illustrations, for a more exact account of the muscles in this region than the somewhat unsatisfactory condition of the parts in Beluga permitted us to draw up.

Pelvic peritoneum almost completely envelopes the rectum to within 2 inches from the anal orifice, whence it is reflected to the vagina, the superior wall of which it invests to a corresponding extent. The inferior wall of the vagina is likewise covered by the serous membrane as far back as the base of the bladder. It may then be traced along the superior surface of that viscus from which it is reflected to the anterior abdominal wall, the whole of the lower surface of the bladder being thus devoid of peritoneal investment. The broad ligament of the uterus is arranged in the usual manner, and attaches the viscus to the lateral abdominal wall. Posterior to the ovary the peritoneum of the ligamentum latum is thick and leathery, but towards the free margin of the latter it is thin and transparent.

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[*] IV. 146.

[†] II. p. 285.

[‡] II. p. 288.

Mamma.[*]—The mammary gland, as usual in cetacea, lies alongside of the vulva; it measures 3 inches in length. The nipple is of small size, and is concealed in a slight depression of the integument 1¼ inch from the margin of the genital fissure.

In respect of this gland Beluga does not differ from other cetacea. In RISSO's Grampus Dr MURIE[†] describes the erector clitoridis muscle as being functionally a compressor of the mammary gland; but in Beluga this muscle lies altogether on a deeper plane than the gland, and in close contact with the crus clitoridis, and cannot therefore act in the manner indicated.

MALE GENERATIVE ORGANS.

These we have not ourselves had an opportunity of examining. With the view, however, of rendering the anatomical description of Beluga as complete as possible, we venture to transcribe the following observations by Dr BARCLAY[‡] upon the male genitals :—

"The *testicles* we found within the abdomen, of an oblong shape, and lying close by the sides of the intestine, near its extremity. They were 4 inches in length, and the same in circumference. The *penis* was conical; at the apex 1½ inch in circumference, but 4 in circumference towards the base, near to which it exhibited a sigmoid flexure, owing to two very powerful muscles that seemed to have performed the office of retractors. Through its whole extent it was soft and flexible, without either a bone or a cartilage."

This description, incomplete as it is, seems to show that in respect of the male organs Beluga does not differ materially from *Globiocephalus*,[§] *Lagenorhynchus*,[||] and the other toothed whales.

CONCLUDING REMARKS.

In the present imperfect state of our knowlege of cetacean anatomy, it is impossible to arrive at any definite conclusion with regard to the relation in which Beluga stands to other genera. At the same time, a reference to the comparative observations contained in the foregoing pages serves to show that, so far as the soft parts are concerned, Beluga in many respects presents a close resemblance to *Grampus* and to *Globiocephalus*, whilst it differs from both in several minor particulars. From an examination of the skeleton, Professor

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[*] According to FLOWER, the male mammary glands of cetacea were first discovered in Beluga by PALLAS.—*P. Z. S.* i. 865.

[†] X. p. 122.

[‡] VIII. p. 384.

[§] IV. p. 164.

[||] V. p. 149.

FLOWER[*] concludes that "the Narwhal and the Beluga appear to separate themselves from all the rest by certain well-marked structural conditions, especially in the characters of the cervical vertebræ. As these two animals are in almost every part of their skeleton nearly identical," Professor FLOWER is disposed "to unite the two genera into a distinct subfamily, placing it next to the Platanistidæ." Unfortunately, such information as we possess regarding the soft parts of the Narwhal is of too imperfect a character to admit of the comparison being followed out. If, however, the number and arrangement of the nasal sacs, as forming an element in the determination of the affinities of different cetaceans, is deserving of the importance attributed to them by some writers, those of Beluga certainly seem to associate that genus with *Monodon,* and to separate it from the other genera above named. It should, however, be noted that the subdivision of the trachea into *four* bronchi in *Monodon* is widely different from that which obtains in Beluga and in every other toothed whale of which we have any knowledge, with the single exception of *Pontoporia.* In view of the scantiness of the information at our disposal regarding the anatomy of *Monodon,* we deem it inexpedient to pursue the comparison further at present, and shall leave the determination of the exact affinities of Beluga to be decided by future observers.

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[*] Trans. Zool. Soc., vol. vi. p. 115.

EXPLANATION OF PLATES.

PLATE VII.

Figure 1. Internal female organs of generation, ¼ natural size. *v.* vagina; *u.* uterus; *c.u. c.u.* cornua uteri; *f.t. f.t.* Fallopian tubes; *a.o. a.o.* their abdominal openings; *o.* ovary; *r.* rectum.

Figure 2. Vagina and uterus laid open, ½ natural size. *o.u.* os uteri; *v.f.* folds of vaginal mucous membrane.

Figure 3. External female organs of generation, ½ natural size. *c.* clitoris; *l.m.* labia minora; *n.* nipple; *v.* orifice of vagina; *a.* anus.

Figure 4. Stomach laid open. The figures 1, 2, 3, 4, 5 indicate the different cavities; *œ.* œsophagus; *d.* duodenum; *l.* liver; *h.d.* hepatic duct; *p.d.* pancreatic duct.

Figure 5. Exterior of stomach. The figures 1, 2, 3, 4, 5 indicate the gastric compartments; *œ.* œsophagus; *d.* duodenum; *l.* liver; *p.p.* pancreas.

Figure 6. Spleen, about ½ natural size.

Figure 7. Kidney, ¼ natural size.

PLATE VIII.

Figure 1. Tongue and larynx. *L.* larynx; *T.* tongue.

Figure 2. Deep muscles of tongue and hyoid bone. *G.g.* genio-glossus; *St.g.* stylo-glossus; *Hy.g.* hyo-glossus; *My.hy.* mylo-hyoideus; *Th.hy.* thyro-hyoideus; *C.th.* crico-thyroideus; *St.th.* sterno-thyroideus; *I.h.* interhyoideus; *. muscle described on page 411 of the text.

Figure 3. Superficial muscles of tongue and hyoid bone. *G.hy.* genio-hyoideus; *My.hy.* mylo-hyoideus; *St.hy.* sterno-hyoideus.

Figure 4. Hyoid bone and laryngeal cartilages seen from below, about ¼ natural size. *B.h.* basi-hyal; *T.h.* thyro-hyal; *C.h.* cerato-hyal; *St.h.* stylo-hyal; *T.* thyroid cartilage; *C.C.* cricoid cartilage.

Figure 5. Blow-hole and nasal sacs seen from within, ½ natural size. *B.* blow-hole; *N.S. N.S.* nasal sacs.

Figure 6. Laryngeal cartilages, lateral view. *A.* arytenoid cartilage; *E.* cartilage of epiglottis; *T.* thyroid cartilage seen in section; *C.* cricoid cartilage.

Figure 7. Trachea and lungs. *T.* trachea; *L.L.* lungs; *L.G.* pulmonic lymphatic glands.

XII.—*On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth—their Structure in the Field and under the Microscope.* By Professor Geikie, LL.D., F.R.S., Director of the Geological Survey of Scotland. (Plates IX., X., XI., XII.)

(Read 3d February and 2d June 1879.)

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INTRODUCTION.

The geographical area embraced in the present memoir forms a well-marked basin traversed along its centre by the estuary of the Forth. It is bounded on the north by the chain of the Ochil Hills, on the south by the range of the Pentland and Lammermuir uplands. Towards the west it joins along a low watershed the basin of the Clyde, while eastwards it dips under the waters of the North Sea. Within this defined space the Carboniferous rocks occupy what may be described as one great synclinal trough, varied by innumerable smaller synclines and anticlines. Save where cut out by powerful dislocations, their lower members rise up along the margins of the basin, while their highest portions cover a smaller area in the centre. The older formations forming the northern and southern boundaries of the area belong chiefly to the Lower Old Red Sandstone, in the Lammermuir district to the Lower Silurian. The Carboniferous rocks everywhere rest upon them unconformably.

Within the region thus limited the Carboniferous system in its Scottish type is admirably displayed in numerous natural and artificial sections. Every great group of strata can be satisfactorily examined, and thus a thorough knowledge can be obtained of the detailed stratigraphy. One of the most noteworthy features in the geological structure of this part of Scotland is the abundance and variety of the volcanic rocks associated with the older half of the Carboniferous system. For a protracted geological period the site of the present basin of the Firth of Forth was occupied by numerous volcanic vents, emitting showers of tuff and streams of lava, which were duly interstratified with the contemporaneous sediments. A record has thus been preserved of a remarkable phase of palæozoic volcanic activity. Affording means of comparison with Tertiary and modern volcanic phenomena, down even into many points of minute detail, it enables us to decide whether volcanic action was essentially different in early geological times from its present conditions. Traces of the influence of WERNER's doctrines regarding the modern and abnormal character of volcanic action may be detected even yet in modern geological literature. It has seemed to me that a useful end might be served by subjecting the well-developed volcanic series in the Carboniferous system of the Forth district to rigid scrutiny in the field and detailed study with the microscope. The results of this investigation I now lay before the Society.

From the number and variety of the natural sections near Edinburgh the igneous rocks of this region have been the subject of numerous observations from the early days of geology down to the present time. The mere enumeration of the titles of the various publications on the subject would form a long list. As I shall have occasion elsewhere to refer to these various papers, it will be sufficient at present to point out that the igneous rocks of the Edinburgh district have afforded materials for some well-known researches in theoretical and structural geology, and to allude to a few of the more important descriptions of them. These rocks formed the subject of some of HUTTON's early observations, and furnished him with the facts from which he established the igneous origin of "whinstone."[*] They supplied PLAYFAIR with numerous apt illustrations in support of HUTTON's views, and he seems to have made himself thoroughly familiar with them.[†] In the hands of Sir JAMES HALL they formed the groundwork of those remarkable experiments on the fusion of whinstone which may be said to have laid the foundation of experimental geology.[‡] In the controversies of the Neptunian and Plutonian schools these rocks were frequently appealed to by each side in confirmation of their respective dogmas. The appointment in 1804 of JAMESON to the Chair of Natural History in the Edinburgh University gave increased impetus to the study of the igneous rocks of this region. Though he did not himself publish much regarding them, we know that he was constantly in the habit of conducting his class to the hills, ravines, and quarries of the neighbourhood, and that the views which he taught were imbibed and extended by his pupils.[§] Among the early writers the names of ALLAN,[‖] TOWNSON,[¶] and Lord GREENOCK,[**] deserve especial mention.

The first broad general sketch of the igneous rocks of the basin of the Forth was that given by HAY CUNNINGHAM in his valuable Essay on the Geology of the Lothians.[††] He separates these rocks into two series, the Felspathic, including porphyry and clinkstone, and the Augitic or Trap rocks. To these he adds Trap-tufa, and considers it identical in origin with modern volcanic tuff. It is the eruptive character of the igneous rocks on which he specially dwells, showing by numerous sections the effects which the protrusion of the molten masses have had upon the surrounding rocks. He does not attempt to separate the intrusive from the interbedded sheets, nor to form a chronological arrangement of the whole.

Still more important was the sketch given by MACLAREN, in his classic "Geology of Fife and the Lothians,"[‡‡] a work far in advance of its time. The

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[*] Hutton's "Theory of the Earth," vol. i. p. 155, *et seq.*

[†] Playfair's "Illustrations of the Huttonian Theory," § 255, *et seq.*

[‡] See "Trans. Roy. Soc. Edin." (1805), vol. v. p. 43.

[§] See "Mem. Wern. Soc." ii. 178, 618; iii. 225; "Edin. Phil. Journ." i. 138, 352; xv. 386.

[‖] "Trans. Roy. Soc. Edin." (1811), vi. p. 405.

[¶] "Tracts and Observations in Natural History and Physiology," 8vo, Lond. 1799.

[**] "Trans. Roy. Soc. Edin." (1833), xiii. p. 39, 107.

[††] "Mem. Wern. Soc." vii. p. 1. Published separately, 1838.

[‡‡] Small 8vo, Edin. 1838, first partly published as articles in the *Scotsman* newspaper.

author clearly recognises that many of the igneous rocks were thrown out contemporaneously with the strata among which they occur. He constantly seeks for analogies among modern volcanic phenomena, and presents the igneous rocks of the Lothians not as so many petrographical varieties, but as monuments of different phases of volcanic action previous to the formation of the Coal-measures. His detailed descriptions refer chiefly to Arthur Seat and the Pentland Hills, to which alone the work was originally intended to refer. They may be cited as models of exact and luminous research. The portions referring to the rest of the basin of the Forth do not profess to be more than a mere sketch of the subject.

The first chronological grouping of all the intercalated sheets of igneous rock in the region was that made by myself for the Geological Survey. The general order of succession of the strata was carefully worked out, and the horizon of each sheet of volcanic rock could thus be definitely fixed. In the memoirs illustrative of Sheets 32, 33, and 34 the general structure of the country from Linlithgow to Berwick-on-Tweed was traced, and the part taken by the igneous rocks was there described.

Since the appearance of the maps and memoirs of the Survey, prolonged study of igneous rocks in other parts of Britain and abroad has given me further insight into the history of volcanic action in this district of Scotland. The application of microscopical examination has opened up a new field of inquiry, giving new methods of mineralogical analysis and comparison, and new aids in the investigation of ancient volcanic processes. I propose therefore, in the present memoir, to offer to the Society a general view of the volcanic phenomena associated with the Carboniferous rocks in the basin of the Forth, derived on the one hand from a study of the rocks in the field, and on the other from an examination and comparison of them under the microscope.

The subject thus divides itself naturally into two parts,—1st, The larger relations of the rocks to each other and to the associated stratified formations, including the geological structure of the masses, their chronology and the succession of events of which they are memorials; 2d, The minute and internal composition and relations of the rocks, chiefly as revealed by the microscope. The former subdivision may be termed Stratigraphical, the second Petrographical.

I. STRATIGRAPHY.

A. The Carboniferous Strata of the Basin of the Firth of Forth.

The Carboniferous system of Central Scotland consists of the following subdivisions :—

Coal-measures.	Upper red sandstones, nearly devoid of coal-seams.
	Coal-bearing sandstones, shales, &c. (upper or Flat coals).
Millstone Grit.	Thick white and reddish sandstones and grits.
Carboniferous Limestone Series.	Sandstones, shales, &c., with coal seams and three thin seams of encrinal limestone.
	Sandstones, shales, &c., with numerous seams of coal and ironstone (lower or Edge coals).
	Thick encrinal limestones, with some seams of coal.
Calciferous Sandstone Series.	White sandstones, oil-shales, some thin coals, and limestone (Burdie House).
	Red and grey sandstones and cornstones (Upper Old Red Sandstone) resting unconformably on Lower Old Red Sandstone.

At the outset it deserves to be kept in view that not only the basin of the Forth but the whole of central Scotland had already, long before the Carboniferous period, been the scene of some of the most stupendous volcanic eruptions which have been chronicled among the rocks of Great Britain. During the time of the Lower Old Red Sandstone the wide lake or inland sea which extended between the base of the Highland mountains and the Southern uplands was marked by two long lines of volcanic vents, from which prodigious volumes of lava and ashes were emitted. Even now, in spite of all denudation and dislocation, more than 5000 feet of volcanic material can be measured at the northern end of the Pentland Hills without reaching the top. In the Ochil Hills a depth of more than 6000 feet of similar rocks can be seen, and yet the bottom is not reached. Full details regarding these volcanic masses will be given in the second part of my Memoir on the Old Red Sandstone of Western Europe. In the meantime it is evident, that in tracing the history of the Carboniferous volcanoes, we must regard them as the diminished successors of an earlier series in the same region. That earlier series, however, seems to have been entirely closed long before the oldest of the Carboniferous eruptions. The two volcanic groups of rock are separated by a strong unconformability and extensive denudation, doubtless indicative of an interval of protracted duration.

In looking at the chronological distribution of the volcanic masses, we find that the true interbedded, as distinguished from the intrusive sheets, belong entirely to the two lower subdivisions of the Carboniferous system. They begin about the top of the red sandstone series which forms the base of the system, and continue at intervals till towards the top of the Carboniferous Limestone series, when they entirely cease. No truly interbedded lava or volcanic tuff has been found in either the Millstone Grit or the Coal-measures. Yet both these subdivisions have been invaded by extensive intrusive sheets. The date of the intrusion cannot be satisfactorily settled. It is evident, however, that between the volcanic action, represented respectively by the older and the later Carboniferous formations, an enormous interval must have elapsed. This question will be discussed in a subsequent part of the present paper.

The circumstances under which the older half of the Carboniferous system of central Scotland was accumulated require to be kept in mind when we attempt to follow the history of the contemporaneous volcanic phenomena of the region. At the beginning of the Carboniferous period, the conditions under which the Old Red Sandstone had been accumulated still in part continued. The great lacustrine basin in which the 20,000 feet of Lower Old Red Sandstone had been deposited had been in great measure effaced. But comparatively shallow areas of fresh or brackish water occupied its site. Its conglomerates and sandstones had been uplifted and fractured. Its vast ranges of volcanic material, after being deeply buried under sediment, had been once more laid bare, and now extended as ridges of land, separating the pools and lagoons which they supplied with sand and silt. We know little as yet of the flora which at the close of the long Old Red Sandstone period covered these ridges. It probably closely resembled that which, succeeding it, has been preserved in the sandstones and shales of the upper group of the Calciferous sandstones. Of the fishes, however, which frequented the waters, some knowledge has been gathered from the well-known sandstone of Dura Den. With many characteristic changes and differences, these fishes retain much of the peculiar type of the older divisions of the Old Red Sandstone. Though the strata in which they lie pass insensibly into and are intimately bound up with the overlying Carboniferous beds, the fossils themselves have an unmistakable Old Red Sandstone facies.

The red sandstones at the base of the Carboniferous system are almost everywhere unfossiliferous. Beyond Cockburnspath they have yielded a few scales of *Holoptychius* and other forms like those of Dura Den. Elsewhere their barren monotonous character contrasts them with the dark shales and white sandstones of the overlying group of rocks. That they were laid down on a very uneven floor is shown by the way in which they are overlapped by succeeding strata. Thus at the south end of the Pentland Hills they attain a thickness of upwards of 1000 feet, but only three miles towards the south they have entirely disappeared, and the Lower Old Red Sandstone is directly covered by the Carboniferous Limestone.

With the close of the epoch in which these red deposits were accumulated a great change took place in the geography of the Forth basin. Concentration of the water in the enclosed lagoons, and precipitation of iron-oxide amid the gathering sand and silt no longer prevailed. The sheets of water became more continuous, and were liable at intervals to irruptions of the sea. A more copious rainfall, at the same time, may perhaps be inferred from the thick zones of white sandstone, occasional bands of fine conglomerate, and abundant seams of shale. The constantly varying aspect of the strata must at least indicate much more varied climate and conditions of denudation and deposition than are presented to us by the monotonous barren red sandstones. The muddy floor of the shallow water must, in many places, have supported a luxuriant growth of vegetation, which is preserved in the occasional seams and streaks of coal. Numerous epiphytic ferns grew on the subærial stems and branches of the lycopodiaceous trees. Large coniferæ clothed the higher grounds, from which the streams brought down copious supplies of sediment, and whence a flood now and then transported huge prostrate trunks of pine.

It was during this condition of things, distinct from that which then prevailed in the rest of Scotland, that the Carboniferous volcanoes began their activity. The basin of the Firth of Forth was gradually dotted over with little volcanic cones, and here and there with long volcanic ridges formed by the confluence of lavas and showers of tuff. The whole area was all the while undergoing a process of slow subsidence. Cone after cone, more or less effaced by the waters which closed over it, was carried down and buried under the growing accumulation of sediment. But new vents of eruption opened elsewhere, throwing out for a time their dust or lava-streams, and then lapsing into quiescence as they slowly sank into the lagoon.

The occasional presence of the sea over some portions of the area is well shown by the occurrence of thin bands of limestone or shale, containing such fossils as *Orthoceras*, *Bellerophon*, and *Discina*. Yet the general estuarine or fresh-water character of the accumulations seems satisfactorily established, not only by the absence of undoubtedly marine forms from most of the strata, but by the abundance of ostracod crustacea (*Leperditia*), forming sometimes thick lenticular seams of limestone, such as might have been formed in distinct limited hollows, by the numerous scales, teeth, bones, and coprolites of small ganoids, and by the crowded remains of terrestrial vegetation, often admirably preserved among the shales.

There can be little doubt that the Calciferous Sandstone series of the Forth basin is a mingled estuarine and marine equivalent of the Lower Limestone shale, and even perhaps of the lower parts of the Carboniferous Limestone of England. The fossils in the marine bands just referred to make this point tolerably clear. But even the red sandstone group below can be shown from evidence, elsewhere obtainable in Scotland, to be coeval with a Carboniferous Limestone fauna outside the present Scottish area. The abundant fauna of the Carboniferous Limestone did not suddenly start into existence. It seems to have spread over the area of England before it had advanced into that of Scotland. It never, indeed, occupied the latter region so long, and so continuously, as it did the English and Irish tracts. Before it spread up towards the Highlands, it had been borne northward in excessive overflows of the sea, but did not succeed in establishing itself until the close of the Calciferous Sandstone series. At that time, a general subsidence of central Scotland appears to have taken place. A clear but shallow sea covered most of the ground between the chain of the Ochil and Lammermuir hills. At this epoch, the thick lower limestones were formed, which can now be traced continuously over so large an area. But that the sea did not obtain prolonged possession of the area is shown by the intercalation of sandstones, shales, and coal-seams among the limestones, and by the thick mass of similar strata under which the limestones were buried. The coal-seams, with their root-charged under-clays, point to the submergence of many successive terrestrial, or at least swampy surfaces, which had appeared over the site of the buried crinoid and coral limestones.

These changes of physical geography were accompanied in some places by abundant and continuous volcanic action. But the number of actual vents had decreased. Large tracts remained unvisited by any volcanic outbreak. Where the eruptions began most copiously they continued longest. Thus, in the south of Fife, they lingered on until the thick limestones and a considerable depth of the lower coals had been formed. But in Linlithgowshire, where they had been even more profusely poured out, they appeared intermittently, and on a gradually waning scale, until after all the lower coals had been laid down.

Before the Carboniferous Limestone series was finally concluded, volcanic action would appear to have ceased everywhere in the region of the Forth Basin. Not a trace of any interbedded volcanic rock has yet been met with in the Millstone Grit or in the Coal-measures. So far as appears, therefore, the outpouring of lava and ashes was entirely confined to the first half of the Carboniferous period. Nevertheless, the numerous intrusive masses of dolerite which traverse even the uppermost parts of the Coal-measures show that volcanic activity recommenced at some subsequent period. I shall be able in the present memoir to adduce new evidence regarding the nature of these much later eruptions. In the east of Fife they have been accompanied by large sheets of tuff which repose unconformably on the upper Coal-measures and the Carboniferous Limestone series, spreading over faulted and much denuded ground. They must thus either be post-Carboniferous, or at least must be separated from the highest remaining portion of the Carboniferous rocks by an enormous interval of time. Though I believe them to be post-Carboniferous, some probably of Permian, others possibly of Miocene date, I have judged it best to include them in the present communication. The Coal-measures, save where covered by these later volcanic sheets, have nothing overlying them but the drifts and other superficial accumulations.

B. Volcanic Districts.

Notwithstanding the limited extent of the Basin of the Firth of Forth, the sporadic character of its volcanic phenomena is singularly striking. Six districts can still be traced, each marked by its own independent eruptions, which differed from those of the neighbouring tracts not only in time, but even in petrographical character. These districts may be distinguished by the following topographical names:—1. Edinburgh; 2. East Lothian or Haddingtonshire; 3. West Lothian or Linlithgowshire; 4. Stirlingshire; 5. West Fife; 6. East Fife. (See Plate IX.)

1. *Edinburgh District.*—The interbedded volcanic masses of this district are confined to the near neighbourhood of Edinburgh, where they form the well-known eminences of Arthur Seat, Calton Hill, and Craiglockhart Hill. They consist both of lavas and tuffs, in beds varying from 10 to 50 feet or more in thickness. Their eruption began about the close of the red sandstone group, at the base of the Carboniferous system in Scotland, for their higher beds are intercalated with and covered by the lower portion of the white sandstone and dark shale group of the Calciferous Sandstones. This epoch was one of great volcanic activity over the southern half of Scotland. During its continuance there were erupted the lavas and tuffs of the Garlton Hills in Haddingtonshire, those which range along the southern flank of the Silurian uplands from near Dunse in Berwickshire, by Kelso, Rubers Law, Langholm, Birrenswark, and the Annan, to the mouth of the Nith at the foot of Criffel. To the same period of volcanic activity must be assigned the older parts of the great sheets of lava and tuff which extend through the north of Ayrshire, Renfrewshire, and Dumbartonshire, by the Kilpatrick and Campsie Fells to Stirling.

Throughout most of these volcanic tracts the lavas were chiefly the so-called "porphyrites," and the tuffs were dull-red or greenish rocks derived from the destruction of these lavas. In the Edinburgh district, the first lavas erupted were anamesites and basalts, and the tuffs were formed of their debris. In the latter half of the volcanic period the lavas became "porphyrites."

It is deserving of notice that the volcanic mass of Arthur Seat lies in the line of the older volcanic ridge of the Pentland Hills, and at a distance of scarcely two miles from the great vent of the Braid Hills. The long interval which separated these Lower Carboniferous volcanoes from those of the Lower Old Red Sandstone still left a weak part near the ancient vent. Through that line of weakness the volcano of Arthur Seat broke out. At a subsequent time, perhaps in the Permian period, another volcanic orifice was opened near, but not quite upon, the same site. From this last opening the upper and newer rocks of Arthur Seat were ejected.*

Owing to the fact that the line of junction between the red sandstones and the overlying upper group of the Calciferous Sandstones is almost everywhere obscured by faults, it is difficult to determine the number of distinct volcanoes in the Edinburgh district. Arthur Seat and Calton Hill no doubt form parts of the ejectamenta of the same vent. I formerly suggested that this vent may be represented by the neck of basalt forming the Castle Rock of Edinburgh. But there may have been another orifice further east, somewhere on the south side of Arthur Seat. I am now disposed to regard the tuff and anamesite of Craiglockhart Hill as the products of a separate vent which lay in the near neighbourhood of that locality, probably a little to the west.

Far to the south-west, on the borders of Lanarkshire, an isolated volcanic cone poured forth basaltic sheets and slight showers of tuff which now form a band, running for several miles, as a boundary between the two groups of the Calciferous Sandstones.

In Plate X. a series of vertical sections is given to show the nature and position of the interbedded volcanic sheets in the Lothians and Fife. From these sections it will be observed that in the Edinburgh district, where there is a maximum depth of about 500 feet of volcanic rocks, these lie near the base of the Carboniferous series. They occur at Arthur Seat, where the first eruption produced a stream of lava (Long Row), followed after an interval by greenish tuffs and volcanic breccias. Beautifully columnar as well as amorphous basalts overlie those fragmental strata, followed by sheets of dark dull-red "porphyrite," which form the remainder of the volcanic series. In the adjacent Calton Hill, the porphyrite beds are more split up with layers of tuff and breccia. (See fig. 24.)

Allusion must be made here to the intrusive sheets and veins which occur

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* Descriptions of the geological structure of Arthur Seat will be found in Maclaren's "Geology of Fife and the Lothians," and in the "Geological Survey Memoir of Sheet 32, Scotland." Mr JUDD has offered an explanation of one part of the history of the hill (Quart. Journ. Geol. Soc., vol. xxxi. p. 131), which I believe to be quite untenable. It will be referred to elsewhere.

in the Edinburgh district. These rocks, though they did not reach the surface, must be regarded as subterranean portions of the volcanic series. Besides the sheets and veins at Arthur Seat, numerous smaller portions occur near Lochend, and underlying the city of Edinburgh. To the west an irregular belt of large sheets runs from the Water of Leith northwards into Fife.

2. *East Lothian District.*—This forms a very distinctly defined area of about 65 square miles. It includes the Garlton Hills, with a few outstanding eminences to the south of these heights, and most of the coast from near Dirleton to Dunbar. As shown in the fifth column (Plate X.), the volcanic masses, filling up most of the interval between the red sandstones and the base of the Carboniferous Limestone, must attain a thickness of possibly 1500 feet, though, owing to the paucity of sections, only an approximate estimate can be made. At the base of this thick pile of material lies a deep series of red and green tuff, resting upon red and white sandstones and red marls. These fragmental accumulations are admirably shown along the coast to the west of Dunbar, and on both sides of North Berwick. Abundantly interstratified in some parts of the tuff are seams of sandstone, blue and green shale, cement-stone and limestone. One thick band of limestone may be traced from near Tynningham House to Whittingham—a distance of about four miles; another patch appears near Rockville House; and a third at Rhodes, near North Berwick.

No fossils have been noticed in these limestones. The calcareous matter, together sometimes with silica, appears to have been supplied, at least in part, by springs, which may be looked upon as having formed part of the volcanic phenomena of the district. Parts of the limestone are vesicular, and contain a decayed zeolite, scattered crystals of pyrite, and cavities lined with dog-tooth spar. Some portions give out a strongly fœtid odour when freshly broken.

After the cessation of the showers of ash and bombs, lava began to flow, and continued to do so with apparently little intermission until the mass of the Garlton Hills had accumulated. No thick zones of tuff, nor interstratified layers of sedimentary rock, can anywhere be seen, separating the successive lava-beds, though it must be owned that the sections of the rocks are few and unsatisfactory. The earliest lavas were dark red, strongly augitic porphyrites. But the remaining, and much the larger portion, were dull-red, purple, pink, grey, brown, yellow, and even white fine-grained porphyrites, and "claystones."

One of the most interesting features in this district is the occurrence of numerous old volcanic orifices round the margin of the area. On the coast, both to the west and east of North Berwick, they may be seen in the form of necks of agglomerate, basalt, or porphyrite. North Berwick Law is a conspicuous example, and the Bass Rock is probably another. A beautiful instance occurs on the headland of St Baldred's Cradle (fig. 6), and several may be observed near Dunbar.* Again, on the south side of the volcanic sheets, a conspicuous neck rises in Traprain Law. As no necks appear among the hills to the south, nor among the red sandstone to the east, it is evident that the cones from which the volcanic mass of East Lothian was poured out formed a connected group in the shallow water at the northern base of the heights of Lammermuir. The lava and tuff occupy nearly the whole of the interval between the red sandstone group and the base of the Carboniferous Limestone series. Volcanic action was thus prolonged in East Lothian for a protracted period after it had died out in the Edinburgh district.

3. *West Lothian District.*—It is remarkable that while on the east side of Arthur Seat and the Pentland Hills not a single volcanic eruption, so far as we know, took place on the Mid-Lothian area during the whole of the Carboniferous period, the ground to the westward continued to be dotted with active vents throughout the deposition of the Calciferous Sandstones and Carboniferous Limestone series. The oldest eruptions of which any trace can be seen proceeded from small cones, chiefly of tuff. Towards the close of the Calciferous Sandstone period the volcanic activity increased. At the same time, the cones extended northwards into Fife. Some of them were of comparatively large size. The Binns Hill of Linlithgowshire, for example, which still forms a prominent elevation, rising to a height of 170 feet above its base, consists of a mass of fine green tuff, at least 350 feet thick, the vent being now filled up with a plug of basalt, which forms the summit of the hill. South-westwards from Binns the volcanic cones were grouped more closely together, and continued to throw out both showers of tuff and streams of basaltic lavas. These volcanic materials were interstratified with the ordinary sandstones, shales, and other strata of the Lower Carboniferous groups. The Burdie House limestone and Houston coal-seam may be traced among them. We can also detect some of the lower thick calcareous zones of the Carboniferous Limestone series, charged with corals, crinoids, and other characterstic fossils. But along one special tract the volcanic sheets so increased in bulk that at last a great bank of lava stretched continuously between Linlithgow and Bathgate, and prevented the deposition of a considerable portion of the coal-bearing section of the Limestone series, which is consequently not represented there, its place being taken by volcanic rocks. The general depression, however, that led to the formation of the thin upper limestones seems to have been accompanied here by a cessation of volcanic action. The latest interbedded lavas and tuffs lie almost immediately below the Calmy Limestone. Volcanic interstratifications die out there, and save in the form of intrusive masses to be immediately referred to, never reappear in any later formation in this district.

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* See "Memoir on East Lothian," *Geol. Survey Memoirs,* chap. v.

The thickness of strata in a section through the most volcanic part of the heights south of Linlithgow is about 2200 feet. It will probably not be an overestimate to place the proportion of lava and tuff in that section at 2000 feet.

Besides the necks and associated portions of igneous matter, the Linlithgow district presents numerous examples of intrusive igneous rocks belonging to an epoch long posterior to that of the Carboniferous volcanoes. They occur in two forms,—1st, As large sheets intruded into the Millstone Grit and Coal-measures; 2d, As dykes running in a general east and west direction through all the other rocks, aqueous and igneous, including even some of the large intrusive sheets. The dykes form a portion of that vast series which traverses Scotland and the north of England, and, as I have elsewhere shown, may with probability be referred to the Miocene period. They therefore do not belong to the subject of the present memoir. The intrusive sheets of later date than the Coal-measures are, as I have said, probably younger than any part of the Carboniferous system, if, indeed, some of them are not overflows from the Tertiary dykes. As they present, however, some interesting features bearing on the subterranean action of igneous matter, I shall include references to them in the sequel.

4. *Stirlingshire District.*—A relation may be traced between this district and that of Linlithgowshire, somewhat similar to what has already been stated to subsist between the Edinburgh and East Lothian volcanic areas. The Stirlingshire ground embraces a small part of the eastern prolongation of the Campsie Fells, which like the Garlton Hills consist chiefly of various "porphyrites" and tuffs of later date than the red sandstones at the base of the Carboniferous system. There can be little doubt that the two latter areas were contemporaneously the scene of the same conditions of volcanic activity. The distance between them is about forty-five miles. Yet, while from these two centres the same kind of volcanic rocks were being copiously ejected, in the intermediate volcanic district of West Lothian all the lavas were of basaltic types, while the tuffs presented the usual characters associated with these pyroxenic rocks. Not a single sheet or dyke of porphyrite has been met with in any part of that district, with the trifling exceptions at Calton Hill and Arthur Seat.

The volcanic history of the Stirlingshire district is sharply divided off into two periods. First comes the great pile of lava and tuff of the Campsie Fells. These immediately to the north of Kilsyth are seen lying conformably upon the upper part of the red sandstone group of the Calciferous Sandstone series. But except at the bottom they seem to be nearly without interstratifications of sandstones or other ordinary sedimentary strata. Their lower portions consist of slaggy porphyrite-lava and thick beds of fine-grained stratified tuff, with some bands of red, green, and grey clays, and cementstone, and a zone of white sandstone. The united depth of this igneous and aqueous series is at least 400 feet. It is succeeded above by about 600 feet of porphyrite in admirably well-defined beds or flows, which are separated as a rule, not by intercalations of tuff, but by the slaggy vesicular surfaces between the successive sheets.[*] Mr B. N. PEACH, in the course of the Geological Survey of this district, ascertained that while the volcanic masses attain a depth of about 1000 feet at Kilsyth, and swell out to far more than that thickness as they are followed westwards, they thin away rapidly eastward until about a mile north of Stirling, or 13 miles from Kilsyth, they disappear altogether, and the Calciferous Sandstone series closes up without any igneous intercalation. Nothing could show more strikingly the remarkably local character of the volcanic phenomena with which we are here concerned.

The second part of the volcanic history of the Stirlingshire district is represented by the numerous thick sheets of dolerite and other pyroxenic rocks which extend from the neighbourhood of Kilsyth, round the base of the Campsie Fells to beyond Stirling. These masses have been intruded among the Carboniferous Limestone series of strata, probably at a time before the consolidation and disturbance of these strata, seeing that they have been faulted and bent together with them.[†] They belong to an extensive belt of intruded matter which, keeping not far from the base of the Carboniferous Limestone series, extends to near the east end of the long county of Fife, and forms in its course the prominent eminences of the Cleish, Lomond, and Ceres Hills. We cannot be quite sure of the dates of these masses, some of them no doubt belong to the volcanic phenomena of the Carboniferous period, but some may be post-Carboniferous and even Tertiary.

5. *West of Fife District.*—For the sake of convenience, the volcanic rocks of the county of Fife (leaving out of account at present the intrusive sheets) may be grouped in two districts, separated from each other by the Dysart and Leven coal-fields, in which hardly any volcanic rocks occur. In the west of Fife we are presented with almost a counterpart of the features of West Lothian. From about the time of the Burdie House Limestone, until a considerable part of the upper or coal-bearing part of the Carboniferous Limestone series had been deposited, volcanic eruptions continued to take place there from small cones. One group of such orifices lay in that part of the district now occupied by the Saline and Cleish Hills. Conspicuous cones of fine green tuff remain there among the surrounding strata, to mark the sites of some of the vents. Another and more extensive group lay about six or eight miles eastward in the neighbourhood of Burntisland. In this interesting little area we meet with a series of tuffs and lavas occupying nearly the whole of the interval

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[*] B. N. PEACH, in Explanation to Sheet 31, "Geo. Surv. Scotland," p. 15.

[†] B. N. PEACH, *op. cit.* p. 45.

between the Burdie House Limestone and the lower calcareous bands of the Carboniferous Limestone series. The interstratification of these volcanic materials with the estuarine beds, coal-seams, and marine limestone, can be admirably studied along the coast between Burntisland and Kinghorn. I hardly know any other section where the characters of true lava-streams are more strikingly displayed than in the two miles of shore between Pettycur and Seafield Tower. The hills around Burntisland likewise furnish similarly instructive examples of volcanic necks filled with agglomerate and basalt; also of intrusive sheets, and the effects of dislocation.

It will be observed that in the Saline and Burntisland tracts, volcanic action was contemporaneous with that in West Lothian, and ceased nearly about the same time, probably rather earlier. The thickest pile of volcanic rock in this district is that which lies between Burntisland and Kirkcaldy. It consists, like the bank south of Linlithgow, almost wholly of successive sheets of basaltic lavas, and must have a total thickness of upwards of 1500 feet. Yet, in spite of this considerable mass of igneous matter, its emission was confined within a limited area. The Burntisland lavas stretch southward, the island of Inchkeith being probably a part of the same group; but they did not reach the Edinburgh district, which as we have seen was wholly free from volcanic disturbance, except during the early period of the Arthur Seat eruptions.*

6. *East of Fife District.*—In some respects this is one of the most important volcanic areas in the basin of the Firth of Forth; for it contains an extraordinary number of volcanic vents, many of which have been admirably laid bare along the coast. It extends from the neighbourhood of Leven north-eastwards to St Andrews—a distance of 15 miles, with an average breadth of about 6 miles. In this tract, somewhere about fifty distinct orifices of eruption filled with tuff and agglomerate may be observed, besides many masses of dolerite and basalt, some of which may likewise mark the position of active vents. Many of the details to be given in a succeeding part of this paper regarding volcanic necks have been derived from a study of those in this interesting district.

Next to the number of the vents, the feature which most attracts notice in the east of Fife is the almost total absence of any interbedded volcanic rocks. The necks are hardly ever connected with any surrounding interstratified beds of tuff, such as are so abundant in the other districts. They rise indifferently through many various portions of the Carboniferous formations. In the eastern parishes they pierce some of the lower portions of the Calciferous Sandstone series; in the west they rise through the Coal-measures.

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* A small outlier of tuff among the sandstones on the shore to the east of Cramond may be an exception to the statement in the text; but this mass might belong to some isolated cone between the West Lothian and Fife districts.

In the attempt to ascertain the geological horizon of these volcanic rocks, as we are deprived of the assistance which interbedded sheets afford, we must be content to be able to fix certain limits of time within which the eruptions must have occurred. From St Andrews to Elie a chain of vents may be traced, having the same general characters, and piercing alike the Calciferous Sandstones and the older part of the Carboniferous Limestone series. That these vents must in many cases be long posterior to the rocks among which they rise, is indicated by some curious and interesting kinds of evidence. They are often replete with angular fragments of shale, sandstone, and limestone, of precisely the same mineral characters as the surrounding strata, and containing the same organic remains in an identical state of fossilization. It is clear that the rocks must have had very much their present lithological aspect before the vents were opened through them. Again, the vents may often be observed to rise among much contorted strata, as for example along the crest of a sharp anticlinal arch, or across a synclinal basin. The Carboniferous rocks must thus have been considerably plicated before the time of the volcanic eruptions. In the next place, the vents often occur on lines of dislocation without being affected thereby. They must be posterior, however, not only to these dislocations, but also to much subsequent denudation, inasmuch as they overspread the rocks on each side of a fault without displacement. Hence we conclude with confidence, that the great period of volcanic activity in the East of Fife must have been posterior to most, if not all, of the Carboniferous period.

In the neighbourhood of Largo, further important evidence is presented, confirming and extending this conclusion. The highest member of the upper Coal-measures, consisting of various red sandstones, with red and purple clays, shales, thin coals, and ironstones, is prolonged from the Fife coal-field in a tongue, which extends eastward beyond the village of Lower Largo. It is well displayed on the shore, where every bed may be followed in succession along the beach for a space of nearly two miles. Two volcanic necks, presenting the same features as those which pierce the older portions of the Carboniferous system to the east, rise through these red rocks. We are thus carried not only beyond the time of the Carboniferous Limestone, but to the close of the very latest stage of the Carboniferous period in central Scotland. Connected with these and other vents farther north, there is a large area of tuff which has been thrown out upon the faulted and greatly denuded Carboniferous rocks. It may be traced passing from the red upper Coal-measures across the large fault which here separates that formation from the Carboniferous Limestone, and extending inland athwart different horizons of the latter series. Outlying fragmentary cakes of it may be seen resting on the upturned edges of the sandstones, shales, and coal-seams, even at a distance of some miles towards the north-west, proving that the fragmentary materials discharged from the vents spread over a considerable area. The subjoined section (fig 1), may serve as an illustration of the relation between this sheet of bedded tuff and the underlying rocks.

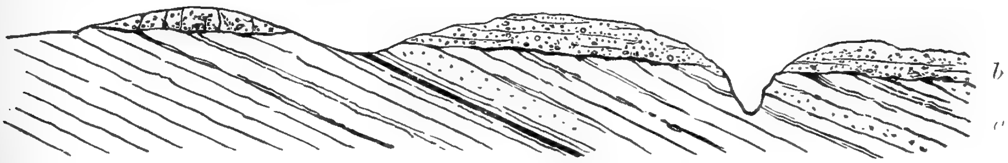

Fig. 1.—Section in brooks between Bonnytown and Baldastard, Largo.
a, Sandstone shales and coals of Carboniferous limestone series ; *b*, Unconformable tuff.

No proof could be more satisfactory that volcanic action was abundant in the east of Fife long after the formation of the latest member of the Scottish Carboniferous system. It is not impossible that some of the detached vents in other parts of the basin of the Firth of Forth may belong to as late a period. I have already suggested that this is probably the date of the later part of Arthur Seat. Some years ago I described a somewhat similar series of vents which pierce the Coal-measures of Ayrshire, and are connected with truly interbedded volcanic sheets in the overlying Permian sandstone series.[*] The Fife volcanoes may with much probability be referred to the same period.

Were there no other evidence to fix the epoch of volcanic activity in the east of Fife, it would be most logical to exclude the volcanic rocks of that district from the list of those belonging to the Carboniferous period. But to the north of Largo, and still more distinctly to the north-east of Leven, sections occur to show the contemporaneous outpouring of volcanic rocks in the Carboniferous Limestone period. The Leven section, seen in a ravine a little to the north-east of the town, is specially important. It presents a succession of red and green fine sandy tuffs, interstratified with fire-clays and sandstones, and containing a zone of basalt in the centre. These rocks lie not far from the top of the Carboniferous Limestone series. They prove that at least in one part of the district, volcanic action manifested itself long before the latest Carboniferous or Permian outbreak. It is quite possible, therefore, that some of these vents, the relations of which to the surrounding rocks are not such as to prove them to be of the latest date, may belong to some part of the time occupied by the deposition of the Carboniferous Limestone. I have not been able to discover any satisfactory means of discriminating them. I believe that if such older vents exist at all, they can form but a small minority among those which, on the grounds already stated, may be assigned to a much later period. But I have glady availed myself of this uncertainty, to include in this memoir an account of the east of Fife volcanic rocks, as they illustrate the phenomena of vents more fully than those of any other district in Scotland.

[*] “Geological Magazine,” vol. iii. p. 243.

Taking the history of volcanic action as a whole within the basin of the Firth of Forth during the Carboniferous period, we can recognise two distinct types in the occurrence of the rocks,—1st, Successive streams of porphyrite lavas were poured out until their united mass attained a thickness of sometimes more than a thousand feet. Comparatively little tuff was ejected over these areas, except here and there, in the earlier stages of eruption. The lavas now form continuous sheets covering wide spaces of country, and rising into conspicuous ranges of hills. This is undoubtedly the prevalent type of the volcanic accumulations in the Carboniferous system in Scotland. The Campsie Fells in the Stirlingshire district, already described, are only the north-eastern extremity of the extensive volcanic plateaux of Dumbartonshire, Renfrewshire, and Ayrshire. The Garlton Hills, in the East Lothian, form a small detached area of the same character, and belonging to the same period; while only about 18 miles to the south-east, on the other side of the Lammermuir uplands, the great volcanic zone of Berwickshire begins with the same kind of rocks, and swells out towards the south-west into the ranges of Roxburgh and Dumfries. 2d, The other type is almost confined to the basin of the Firth of Forth. It consists in the protrusion of numerous detached masses of tuff, and of various augitic lavas never united into wide plateaux or extensive hill-ranges, but all pointing to local and sporadic action. The four districts in the Forth basin where this type is exhibited may, indeed, be viewed broadly as only one area lying between the two districts of the Campsie and Garlton Hills, which so characteristically exemplify the first type.

The local and independent character of the volcanic activity of the second type may be connected here with another feature, which cannot fail to strike the most casual observer. While the great hollow of central Scotland, between the Old Red Sandstone hills on the north, and the Silurian and the Old Red Sandstone heights on the south side, continued for fully a half of the Carboniferous period to be the scene of extraordinary volcanic activity, the eruptions, so far as we can judge, were always confined to the valley. It might be contended that possibly many sheets of tuff or of lava may have been stripped off the bounding hills on either side. But the fact remains, that even were it so, these volcanic materials were erupted from orifices in the valley, and not on the hills. In no case have I ever met with true volcanic necks on the hills on either side of the great central valley.* Denudation could not have removed

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* In the valley of the Nith and its tributary the Carron Water, among the high grounds of Dumfriesshire, necks belonging to the Permian series of volcanoes occur. At the head of Lauderdale, Mr B. N. Peach has observed a small neck coming through the Upper Old Red conglomerate, and possibly connected with the volcanic action in which the Berwickshire and Roxburghshire porphyrites were erupted. But in these cases the orifices have been opened in deep valleys among the hills. [Since this was written, Mr Peach has met with a number of volcanic necks of Lower Carboniferous age in valleys of the Silurian uplands of Roxburghshire, extending to a distance of at least 10 miles from the edge of the lava-sheets.]

them; their absence makes it certain that the numerous volcanic vents were confined to the low grounds.

C. STRUCTURE OF THE VOLCANIC MASSES.

The volcanic rocks associated with the Carboniferous formations in the Basin of the Firth of Forth may be conveniently grouped into four sub-divisions according to their mode of occurrence with reference to the surrounding strata. 1st, *Necks,* that is, masses of volcanic material occupying the space of former vents or orifices out of which the volcanic eruptions proceeded. 2d, *Intrusive Sheets, Dykes,* and *Veins.* These are portions of lava which never succeeded in forcing their way to the surface, but after penetrating some way upward, were arrested in their progress, and consolidated among the rocks. 3d, *Interbedded* or *Contemporaneous Lavas,* that is, masses of molten rock which were emitted at the surface, flowed out there in streams, and consolidated into sheets that lie conformably among the strata with which they are geologically contemporaneous. 4th, *Tuffs,* which occur in large stratified masses, or in small beds, either interstratified with ordinary sedimentary deposits, or accompanying sheets of lava.

1. *Volcanic Necks.*

General Characters.—A volcanic neck is a pipe or funnel which has been blown out of the earth's crust, and has been filled up with the solid materials ejected by the first or subsequent explosions. Viewed geologically, it may be regarded as a column of extraneous material usually in the main of volcanic origin, which descends from the surface to an unknown depth beneath. Unless disturbed by posterior subterranean movements, this column may be considered to be vertical, though any tilt subsequently affecting the rocks of the locality may have given it an inclination to one side. In the basin of the Firth of Forth there has been comparatively little displacement of this kind.

In their external aspect the necks form conspicuous features among the volcanic districts in which they occur. In the great majority of cases they rise as isolated cones or dome-shaped hills, circular or elliptical in outline, and for the most part with smooth grassy slopes. Where a dyke or boss of a hard rock, such as basalt, occurs in them, it usually stands out as a crag or knoll. Where the whole neck consists of an enduring rock of that kind, it forms a bolder, more abrupt eminence. Largo Law (fig. 2) may be taken as a singularly perfect example of the cone-shaped neck. Traprain Law and North Berwick Law illustrate the contour assumed when the rock is of a more enduring kind. One notable exception to the rule that necks form eminences at the surface, is furnished by the remarkable vent which occupies a wide basin-shaped depression among the Campsie Fells. Yet, beyond its margin there occur some conspicuous examples of the usual prominent type, such as the Meikle Binn and Dungoil. Though not by any means the largest or most perfect of the vents in the basin of the Firth of Forth, the Binn of Burntisland presents in detail some of the most strikingly volcanic aspects of scenery anywhere to be seen in that region (fig. 14). Consisting of a dull green granular volcanic tuff, it rises abruptly out of the Lower Carboniferous formations to a height of 631 feet above the sea. Its southern slope has been so extensively denuded, that it presents steep craggy slopes and rugged precipices, which descend from the very summit of the cone to the plain below—a vertical distance of nearly 500 feet. Here and there the action of atmospheric waste has hollowed out huge crater-like chasms in the crumbling tuff. Standing in one of these it is not difficult to realise what must have been the aspect of the interior of these ancient Carboniferous volcanic cones, for the scene at once reminds one of the crater-walls of a modern or not long extinct volcano. The dull green tuff rises around in verdureless crumbling sheets of naked rock, roughened by the innumerable blocks of lava, which form so conspicuous an element in the composition of the mass. Ribs or veins of columnar basalt may be seen shooting up the declivities, and standing out prominently as black shattered walls. The frosts and rains of successive centuries have restored to the tuff its original loose gravelly character. It disintegrates rapidly, and rolls down the slopes in long grey lines of volcanic sand, precisely as it no doubt did at the time of its ejection, when it fell on the outer and inner declivities of the original cone.

Fig. 2.—View of Largo Law from the east (the crag on the left, at the base of the cone, is a portion of a basalt-stream).

The shape of the vents is on the whole circular or oval; but is subject to considerable irregularity. The admirable coast-sections in the east of Fife, between Largo and St Monans, as well as those of the shores of Haddingtonshire, expose many ground-plans of the vents, and permit these irregularities to be closely examined. The accompanying figure (fig. 3), exhibits some characteristic forms of vents. Some of the eccentricities of outline no doubt arose from the irregular way in which the rocks through which an orifice was drilled yielded to the forces of explosion. This is often well shown by the veins and nests of tuff or agglomerate which have been forced into the rents or sinuosities of the orifices. In other cases, however, it is probable that what appears now as one volcanic neck, was the result of a shifting of the actual funnel of discharge, so that the neck really represents several closely adjacent vents. The necks at Kellie Law (fig. 4) show this arrangement very clearly. The Law itself (1) probably consists of two contiguous vents, while a third (2) forms a smaller cone immediately to the east. This slight lateral displacement of the vent has been noticed at many Tertiary and recent volcanic orifices. In the island or peninsula of Volcanello, for example, I observed three craters indicative of successive shiftings of the vent, the most perfect crater marking the latest and diminishing phase of the volcanic activity. The cones at Kellie Law may point to a similar series of events.

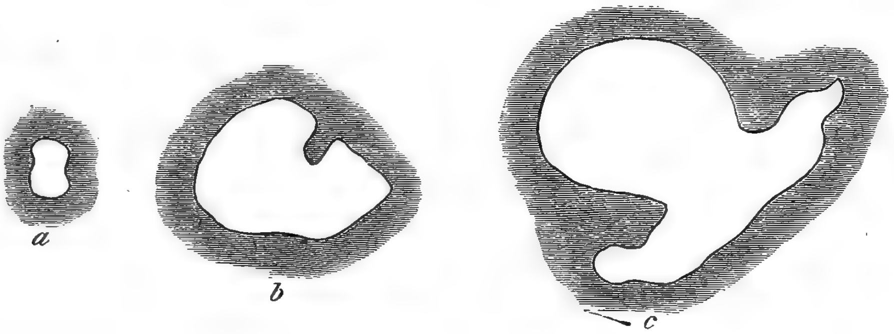

Fig. 3.—Ground plan of volcanic vents.

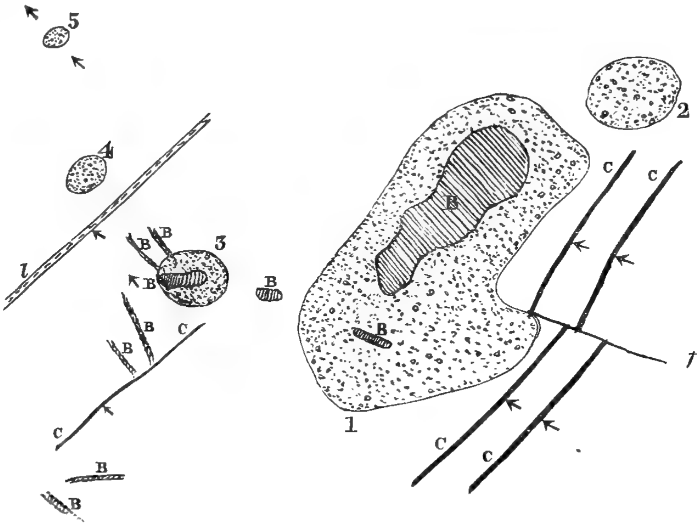

Fig 4.—Plan of volcanic necks at Kellie Law, east of Fife. 1, Kellie Law (tuff); 2, Carnbee Law (tuff); 3, 4, 5, small tuff necks; BB, basalt dykes and sheets; *cc*, coal-seams; *l*, limestone; *f*, fault. The arrows mark the dip of the strata through which the necks have been drilled.

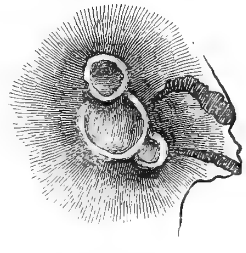

Fig. 5.—Plan of the craters in Volcanello, Lipari Islands.

The size of necks varies from only a few yards up to more than a mile in diameter. In the east of Fife, so remarkable for the number and perfect preservation of these features of volcanic action, one of the smallest and most completely exposed necks occurs on the shore at Newark Castle, near St Monans. It measures only 60 yards in length by about 37 yards in breadth. A ground-plan of it is given in fig. 11, p. 468. Some remarkably small necks may also be seen on the Haddingtonshire coast, particularly in the neighbourhood of Dunbar. One of the largest in central Scotland is that already referred to as occurring among the Campsie Hills between Fintry and Lennoxtown. It is upwards of a mile broad, and is surrounded by other minor necks, several of which form prominent hills.

Materials filling Necks.—These consist of (1) non-volcanic, and (2) volcanic rocks.

1. In some minor necks the vent has been entirely or in great part filled with angular debris of the ordinary rocks of the neighbourhood. In the western neck on the Largo shore, for example, which rises through the red rocks of the upper Coal-measures, the material consists largely of fragments of red sandstone, clay, and shale. Some small necks, exposed in the ironstone workings near Carluke, were found to be filled with debris of black shale and ironstone. At Burntisland fragments of the well-marked cyprid limestone and shale abound. Between Elie and St Monans the tuffs are sometimes almost wholly composed of debris of black shale and encrinal limestone. At Niddry, in Linlithgowshire, large blocks, several yards in length, and consisting of different layers of shale and cement-stone, may be seen imbedded at all angles in the tuff.

Where in these minor vents we encounter only the debris of non-volcanic rocks, we may infer that the volcanic action was limited to the explosion of steam whereby the rocks were dislocated, and an orifice communicating with the surface was drilled through them. No true volcanic rock in these cases appeared, but the pipes were filled up to perhaps not far from the surface by the falling back of the shattered debris. A little greater intensity or farther prolongation of the volcanic action would bring the column of lava up the funnel, and allow its upper part to be blown out as dust and lapilli; while still more vigorous activity would be marked by the rise of the lava into rents of the cone or its actual outflow at the surface. Every gradation in this scale of progress may be detected among the Carboniferous volcanoes of this region.

But though large cones might be built up by the long-continued emission of volcanic products, the first stage in these, as in the minor vents, must always have consisted in the perforation of the solid crust by explosion, and the consequent production of debris from the disrupted rocks. We may therefore expect that underneath the pile of thoroughly volcanic ejections traces of the first explosion must exist. I have been much struck with the fact that in the east of Fife such traces may frequently be found here and there on the outside of the vents. At Largo, and again between Elie and St Monans, I have observed that in the ground-plan exposed upon the shore the mass of material adhering to the wall of a neck often consists largely or even wholly of debris of sandstone, shale, and limestone, while the central and chief mass is made up of green tuff or agglomerate, with occasional pieces of the surrounding stratified rocks scattered through it. It seems probable, therefore, that the sections of these Fife necks, now exposed by the present beach, do not lie far below the original crater-bottoms.

Some light might be expected to be thrown upon the phenomena in an active volcanic chimney by the condition of the fragments of recognisable sedimentary rocks imbedded in the ejected debris which has filled up the orifice. But the assistance from this source is neither so full nor so reliable as could be wished. In a great many cases indeed the fragments of shale, sandstone, and other sedimentary strata are so unchanged that they cannot on a fresh fracture be distinguished from the parent beds at a short distance from the vent. The *spirifers*, *lingułæ*, crinoids, cyprid-cases, ganoid scales, and other fossils, are often as fresh and perfect in the fragments of rock imbedded in tuff as they are in the rock *in situ*. In some cases, however, distinct, and occasionally even extreme, metamorphism may be detected, varying in intensity from mere induration to the production of a crystalline texture. The amount of alteration has depended not merely upon the heat of the volcanic vent, but also in great measure upon the susceptibility of the fragments to undergo change.

My friend Dr HEDDLE endeavoured to estimate the temperature to which fragments of shale, &c., in tuff-necks of the Fife coast had been subjected. He found that the bituminous shales had lost all their illuminants, and of organic matter had retained only some black carbonaceous particles; that the encrinal limestones had become granular and crystalline; that the sandstones presented themselves as quartzite, and that black carbonaceous clays showed every stage of a passage into Lydian-stone. He inferred from the slight depth to which the alteration had penetrated the larger calcareous fragments, that the heat to which they had been exposed must have been but of short continuance. As the result of his experiments, he concluded that the temperature at which the fragments were finally ejected from the volcanic vents probably lay between 660° and 900° Fahr.*

It may be perhaps legitimate to infer that while the fragments which fell back into the volcanic funnel, or which were detached from the sides of the vent, after having been exposed for some time to intense heat under considerable pressure, would suffer more or less metamorphism, those on the other

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* "Trans. Roy. Soc. Edin." xxviii. p. 487.

hand, which were discharged by the æriform explosions from the cool upper crust, on the first outburst of a vent, would not exhibit any trace of such a change. Where, therefore, we meet with a neck full of fragments of unaltered stratified rocks, we may suppose it to have been that of a short-lived volcano; where, on the other hand, the fragments are few and much altered, we may infer that they mark the site of a vent which continued longer active.

2. The volcanic rocks of the necks consist occasionally of (*a*) some form of lava, but more usually of (*b*) fragmentary materials, with or without veins and pipes of lava.

(*a*) In various parts of the Basin of the Firth of Forth occur circular or oval bosses of basalt, dolerite, or porphyrite, which exactly resemble in contour the typical necks of tuff, and occur among interstratified rocks in such a manner as to suggest that they mark the sites of volcanic vents. Traprain Law and North Berwick Law are conspicuous examples. Each of these eminences rises in the midst of tuffs and lavas, and may not improbably be a portion of the lava column which rose in a volcanic pipe. A smaller but very perfect example (fig. 6) occurs on the shore to the east of North Berwick Law.* The Castle rock of Edinburgh may be another. In these cases we probably see a deeper part of the pipe than that in which fragmentary materials accumulated.

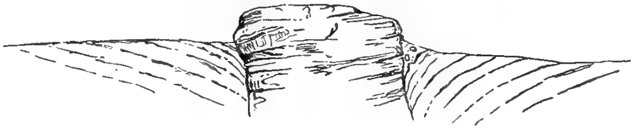

Fig. 6.—Section of Porphyrite neck, in sandstones, Shore of Haddingtonshire.

(*b*) In the great majority of cases the necks are filled with fragmentary volcanic detritus. Sometimes this material consists of a coarse utterly unstratified mass or agglomerate of different lava blocks, angular and subangular, varying in size up to a diameter of a yard or more. The later agglomerate of Arthur Seat may be taken as an illustration of the coarsest variety. In other cases it is a breccia of small angular and subangular lava fragments. Most frequently it is a more or less compact or gravelly tuff, composed of a fine comminuted paste of volcanic dust and sand, full of rounded and subangular blocks and bombs of basalt, porphyrite, or other form of lava. In the east of Fife some of the necks contain a remarkable compact volcanic sandstone, composed of the usual detritus, but weathering into spheroidal crusts so as externally to be readily mistaken for some form of basalt rock. There can be little doubt that this variety of rock was originally a volcanic mud. The lithological details of the tuffs, however, will be given in a later part of this memoir.

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* See "Geology of East Lothian," *Geological Survey Memoir*, p. 40.

It is to be observed that the tuff in the necks of each district partakes of the nature of the lava emitted in that district. In the East Lothian and Stirlingshire areas, for example, where the lavas were the so-called porphyrites, the tuff consists of the debris of these rocks. Elsewhere among basaltic lavas, the tuffs have a characteristic dirty green colour, and in this as well as in other respects show that they have been derived from these rocks. The ejected fragments contained in the tuffs bear the same relation to the surrounding lavas. In those cases where, as in so many of the vents of the east of Fife, no lava flowed out at the surface, we can yet tell from the character of the abundant ejected fragments what was the nature of the molten rock which ascended the volcanic chimney, and produced by its ebullition the abundant showers of tuff.

The lava blocks in the tuffs and agglomerates are usually rounded or subangular. Pear-shaped blocks or flattened discs or hollow spherical balls are hardly ever to be observed, though I have noticed a few examples in the tuffs of Dunbar and Elie. A frequent character of the blocks is that of roughly rounded, highly amygdaloidal pieces of lava, the cellular structure being specially developed in the interior, and the cells on the outside being often much drawn out round the circumference of the mass. Blocks of this kind, two or three feet in diameter, may be seen at some of the Elie vents. They were probably torn from the cavernous, partially consolidated, or at least rather viscous, top of a lava column. Most of the stones, however, suggest that they were produced by the explosion of already crusted lava, and were somewhat rounded by attrition in their ascent and descent. The vents filled with such materials must have been the scene of prolonged and intermittent activity; successive paroxysms resulting in the clearing out of the hardened lava column in the throat of the volcano, and in the rise of fresh lava, with abundant ejection of dust and lapilli. Corroborative evidence that the intervals of explosion were separated by long periods of quiescence is furnished by the fragments of wood to be afterwards referred to, and likewise by the numerous pieces of stratified tuff frequently to be noticed imbedded with the other debris in a neck. These angular blocks of older tuff resemble in general petrographical character parts of the tuff among which they are imbedded. There can be little doubt that they are portions of the volcanic debris which solidified inside the crater, and which was blown out in fragments by subsequent explosions. In a modern volcano a considerable amount of stratified tuff may be formed inside the crater. The ashes and stones thrown out during a period of activity fall not only on the outer slopes of the cone, but on the steep inner declivities of the crater, where they arrange themselves in beds which dip at high angles towards the crater bottom. This feature is well seen in some of the extinct cones in the Neapolitan district. At Astroni, for example, great sheets of well-bedded trachytic tuff lie on the inner slopes of the crater. (See fig. 9.)

One of the most curious and puzzling features in the contents of the tuff necks is the occurrence there of crystals and fragments of minerals, often of considerable size, which do not bear evidence of having been formed *in situ*, but rather of having been ejected with the other detritus. Dr HEDDLE has noticed this fact, and has described some of the minerals which occur in this way. The following list comprises the species which he and I have noticed chiefly in the vents of the East of Fife:—

Hornblende, in rounded fragments of a glassy black cleavable variety.
Augite, sometimes in small crystals, elsewhere in rounded fragments of an augitic glass.
Orthoclase (Sanidine), abundant in worn twin crystals in the tuffs of the East of Fife.
Biotite.
Pyrope, in the tuffs (and more rarely in the basalts) of Elie.
Nigrine, common in some of the dykes, more rarely in the tuffs of Elie.
Saponite, Delessite, and other decomposition products.
Semi-opal, one specimen found in later tuff of Arthur Seat.
Asphalt, abundant at Kincraig, near Elie.
Fragments of wood, with structure well preserved, may be included here.

In his paper on the Felspars, Dr HEDDLE has described from the neck of tuff at Kinkell, near St Andrews, large twin crystals of a glassy orthoclase, which are invariably much worn, and preserve only rudely the form of crystals. He justly remarks that they have no connection with drusy cavity, exfiltration vein, or with any other mineral, and look as if a portion of their substance had been dissolved away. Internally, however, they are quite fresh and brilliant in lustre, though sometimes much fissured.*

The tuffs at Elie are full of similar crystals. I obtained from one of the necks east of that village, a specimen which measures 4 inches in length, 3½ in breadth, and 2¼ in thickness, and weighs about 2 lbs. It is, however, a well-striated felspar. From the same tuff I procured an orthoclase twin in the Carlsbad form. All the felspar pieces, though fresh and brilliant internally, have the same rounded and abraded external appearance.

The fragments of hornblende form a characteristic feature in several of the Elie dykes (to be afterwards described), and in the neighbourhood of these intrusive rocks occur more sparingly in the tuff. It is a glossy-black cleavable mineral, in rounded pieces of all sizes, up to that of a small egg. Dr HEDDLE obtained a cleavage angle of 124° 19′, and found on analysis that the mineral was hornblende.†

Augite occurs sparingly in two forms among the necks. Some years ago, I

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* Trans. Roy. Soc. Edin. vol. xxviii. p. 223.

† *Op. cit.* xxviii. 522.

obtained small crystals from the red upper tuff of Arthur Seat, recalling in their general appearance those of Somma. Lumps of an augitic glass have been found by Dr HEDDLE, sometimes as large as a pigeon's egg, in two of the dykes at Elie, and in the tuff at the Kinkell neck, near St Andrews. He observed the same substance at the Giant's Causeway, both in the basalt, and scattered through one of the interstratified beds of red bole. I recently found much larger rounded masses of a similar augitic glass, but with a distinct trace of cleavage, in a volcanic vent of Upper Old Red Sandstone age, at John o' Groat's House.*

Biotite is not a rare mineral in some of the tuffs. It may be obtained in the stratified tuffs of Dunbar, in plates nearly an inch broad; but the largest specimen I have obtained is one from the same Elie vent which yielded the large felspar fragment. It measures $2\frac{1}{2} \times 2 \times \frac{1}{2}$ inches. These mica tables, like the other minerals, are abraded specimens.

That these various minerals were ejected as fragments, and have not been formed *in situ*, is the conclusion forced upon the observer who examines carefully their mode of occurrence. Some of them were carried up to the surface by liquid volcanic mud, and appear in dykes like plums in a cake. But even there they present the same evidence of attrition. They assuredly have not been formed in the dykes any more than in the surrounding tuff. In both cases they are extraneous objects which have been accidently involved in the volcanic rocks. Dr HEDDLE remarks that the occurrence of the worn pieces of orthoclase in the tuff is an enigma to him. I have been as unable to frame any satisfactory explanation of it.

Arrangement of Materials in Necks of Tuff and Agglomerate.—It might have been thought that in the throat of a volcano, if in any circumstances, loose materials should have taken an utterly indefinite amorphous aggregation. And this is usually the case where these materials are coarse and the vent small. Oblong blocks are found stuck on end, while small and large are all mixed confusedly together. But in the numerous cases where the tuff is more gravelly in texture traces of stratification may usually be observed. Layers of coarse and fine material succeed each other, as they are seen to do among the ordinary interstratified tuffs. The stratification is usually at high angles of inclination, often vertical. So distinctly do the lines of deposit appear amid the confused and jumbled masses, that an observer may be tempted to explain the problem by supposing the tuff to belong, not to a neck, but to an interbedded deposit which has somehow been broken up by dislocations. That the stratification, however, belongs to the original volcanic vents themselves, is made exceedingly clear by some of the coast-sections in the East of Fife. On both sides of Elie examples occur in which a distinct circular disposition of the bedding can be traced corresponding to the general form of the neck. The accompanying

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* *Op. cit.* xxviii. p. 481, *et seq.*

ground plan represents this structure as seen in the neck which forms the headland at the harbour. Alternations of coarse and fine tuff with bands of coarse agglomerate, dipping at angles of 60° and upwards, may be traced round about half of the circle. The incomplete part may have been destroyed by the formation of another contiguous neck immediately to the east. To the west of Earlsferry another large, but also imperfect, circle may be traced in one of the shore necks. A quarter of a mile further west rises the great cliff-line of Kincraig, where a large neck has been cut open into a range of precipices 200 feet high, as well as by a tide-washed platform more than half a mile long. The inward dip and high angles of the tuff are admirably laid bare along that portion of the coast line. The section in which almost every bed can be seen, and where, therefore, there is no need for hypothetical restoration, is as shown in fig. 8.

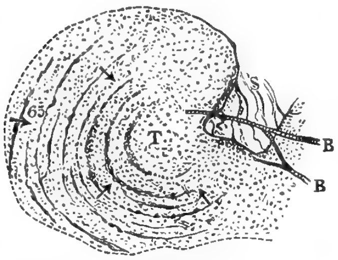

Fig. 7.—Ground-plan of Volcanic Neck, Elie Harbour, showing circular deposition of the stratification.

T, Tuff of the neck, the arrows showing its inward dip, BB, Dykes, S. Sandstones and shales, through which the neck has been opened.

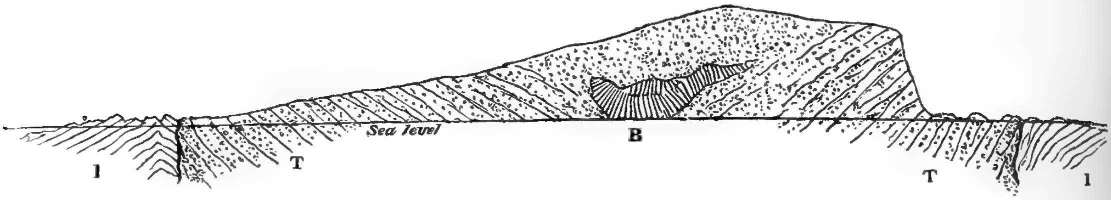

Fig. 8.—Section across the great vent of Kincraig, Elie, on a true scale, vertical and horizontal, of six inches to a mile.

1, Sandstones, shale, &c., of Lower Carboniferous age, plunging down toward the neck T; B, columnar basalt.

I have already referred to the frequently abundant pieces of stratified tuff, found as ejected blocks in vents filled with tuff, and to the derivation of these blocks from tuff originally deposited within the crater. There can, I think, be little hesitation in regarding the stratification of these Fife vents as exhibitions of this same operation. The general dip inwards from the outer rim of the vent strikingly recalls that of some modern volcanoes. By way of illustration, I give here a section of part of the outer rim of the crater of the Island of Volcano, sketched by myself in ascending the mountain from the north side (fig. 9). The crater wall at this point consists of two distinct parts,—an older tuff (*a*), which may have been in great measure cleared out of the crater before the ejection of this newer tuff (*b*). The latter lies on the outer slope of the cone at the usual angle of 30°. It folds over the crest

Fig. 9.—Section of part of crater rim, Island of Volcano.

of the rim, and dips down to the flat tuff-covered crater bottom, at an angle of 37°. These are its natural angles of repose.

Applying modern analogies of this kind, I have been led to conclude that the stratification so conspicuous in the tuff of the Carboniferous vents throughout central Scotland belongs to the interior of the crater and the upper part of the volcanic funnel. These stratified tuffs, on this view of their origin, must be regarded as remains of the beds of dust and stones which gathered within the crater and volcanic orifice, and which, on the cessation of volcanic action, sometimes remained in their original position, or were dislocated, and slipped down into the cavity beneath. That the tuffs consolidated on slopes, perhaps quite as steep as those of Volcano, is now and then indicated by an interesting structure. The larger stones imbedded in the layers of tuff may be observed to have on their fronts in one direction a small heap of coarse gravelly debris, while fine tuff is heaped up against their opposite side. This arrangement doubtless points to deposit on a slope of loose debris, from which the larger blocks protruded so as to arrest the smaller stones, and allow the fine dust to gather behind.

The frequent evidence of great disturbance in the bedding of the tuff within the vents may be connected with some kind of collapse, subsidence, or shrinkage of the materials in the funnel below. That a movement of this nature did take place is shown by the remarkable bending down of the strata round the margins of the vents, as will be described in the sequel.

Dykes, Pipes, and Cakes of Lava in Necks of Tuff and Agglomerate.—The minor vents for the most part contain only fragmentary materials; but those of larger size usually present masses of lava in some characteristic forms. In not a few cases the lava has risen in the central pipe and hardened there into a column of solid rock. Subsequent denudation, by removing most of the cone, has left the top of this broad column projecting as a round knoll upon the hill top. Arthur Seat presents a good example of this structure. Where the denudation has not proceeded so far, we may still meet with a remnant of the cake of lava which sometimes overflowed the bottom of a crater. The summit of Largo Law affords indications of this arrangement. That cone of tuff is capped with basalt, evidently the product of successive streams, which welling out irregularly covered the crater bottom with hummocks and hollows. The knolls are beautifully columnar, and sometimes show a divergent arrangement of the prisms.

But the most frequent form assumed by the lava in the necks is that of veins or dykes running as wall-like bands through the tuff or agglomerate. Many admirable examples might be cited; the most striking and accessible being those of the Fife coast. The shores between Largo and St Monans abound with them. These intruded masses vary in breadth from mere threadlike veins up to dykes several yards in breadth, which sometimes expand into large irregular lumps. They generally consist of some form of basalt (including all the fine varieties of dolerite); now and then, as at Ruddon Point, near Elie, they are amygdaloidal; and it may be observed among them, as among dykes in general, that where the amygdaloidal texture is developed, it is apt to occur most markedly in the central part of the vein, the amygdules running there in one or more lines parallel with the general trend of the mass.

That the basalt of these veins and dykes was sometimes injected in an extremely liquid condition is shown by its frequently exceedingly close homogeneous texture. Within the neck on the shore to the west of Largo, the basalt assumes in places an almost flinty texture, which here and there passes into a thin external varnish of tachylite. A farther indication of the liquidity of the original rock seems to be furnished by the great number of included extraneous fragments here and there to be observed in the basalt.

But besides basalt other materials may more rarely be detected assuming the form of dykes or veins within the necks. Thus, at the Largo neck just referred to, strings of an exceedingly horny quartz-felsite accompany the basalt,—a remarkable conjunction of acid and basic rock within the same volcanic chimney. To the east of Elie some dykes which stand out prominently on the beach consist of an extremely compact volcanic mudstone stuck full of worn twin crystals of orthoclase and pieces of hornblende and biotite. So like is this rock to one of the decomposing basalts, that its true fragmental nature may easily escape notice, and it might be classed confidently as a somewhat decayed basalt. A considerable amount of a similar fine compact mudstone is to be seen round the edges of some of the Elie vents.

A columnar arrangement may often be observed among the basalt dykes. When the vein or dyke is vertical the columns of course seem piled in horizontal layers one above the other. The exposed side of the dyke then reveals a wall of rock, seemingly built up of hexagonal or polygonal, neatly fitting blocks of masonry, as may be seen on the Binn of Burntisland. An inclination of the dyke from the vertical throws up the columns to a proportional departure from the horizontal. Sometimes a beautiful fan-shaped grouping of the prisms has taken place. Of this structure the Rock and Spindle, near St Andrews, presents a familiar example. Much more striking, however, though much less known, is the magnificent basalt mass of Kincraig, to the west of Elie, where the columns sweep from summit to base of the cliff, a height of fully 150 feet, like the Orgues d'Expailly, near Le Puy in Auvergne (fig. 10).

The veins or dykes seldom run far, and usually present a more or less tortuous course. No better example of these characters can be cited than that of the veins on the south front of the Binn of Burntisland (fig. 14). These vary in breadth from 5 or 6 feet to scarcely so many inches. They bifurcate, and rapidly disappear in the tuff, one of them ascending tortuously to near the top of the cliff. They at once recall the appearance of the well-known dykes in the great crater wall of Somma.

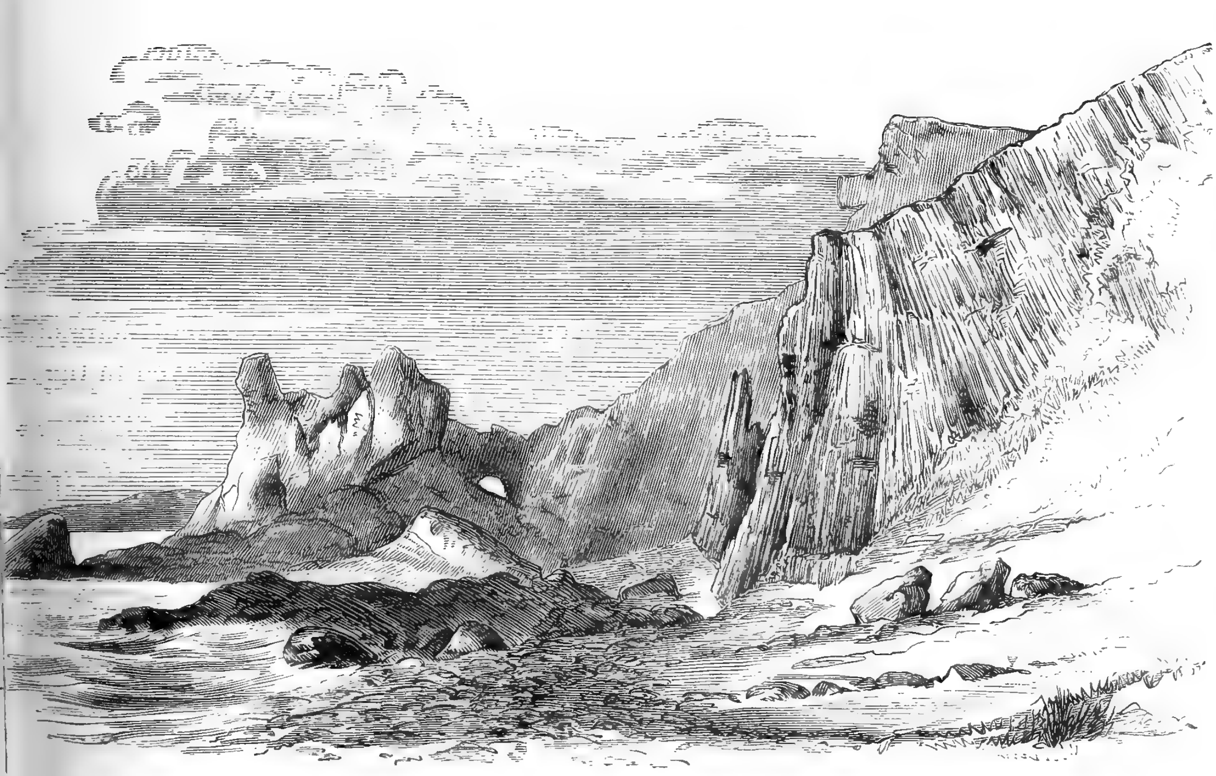

Fig. 10.—Columnar basalt in vent at Kincraig, Fife.

That many of these dykes served as lines of escape for the basalt to the outer slopes of the cone is highly probable, though denudation has usually destroyed the proofs of such an outflow. In some of the Fife necks a distinct radiation of the dykes from the centre of the neck is still traceable. This structure is most marked on the south cone of Largo Law, where a number of hard ribs of basalt project from the slopes of the hill. Their general trend is such that if prolonged they would meet somewhere in the centre of the cone. On the south-east side of the hill a minor eminence, termed the Craig Rock, stands out prominently. It is oblong in shape, and like the dykes, points towards the centre of the cone. It consists of a compact columnar basalt, the columns converging from the sides towards the top of the ridge. It looks like the fragment of a lava-current which flowed down a gully on the outer slope of the cone. (B′ in fig. 13.)

The veins of basalt are not confined to the necks, but may be seen running across the surrounding rocks. The shore at St Monans furnishes some instructive examples of this character. As the veins thin away from the main mass of basalt, they become more close-grained and lighter in colour; and when they enter dark shales or other carbonaceous rocks, they pass into that peculiar white earthy clay-like variety known as "white-rock" or "white-trap."

Junction of the Necks with the surrounding Rocks.—In a modern volcano no opportunity is afforded of examining the effects which have been produced upon the rocks through which the volcanic vent has been opened, except now and then among the detached fragments ejected. But in the Basin of the Firth of Forth a numerous series of coast sections lays bare this relation in the most satisfactory manner. The superincumbent cones have been swept away, and we can examine, as it were, the very roots of the old volcanoes. The margin of a neck or volcanic vent is thus found to be almost always sharply defined. The rocks through which the vent has been drilled have often been cut across, as if a huge auger had been sunk through them. This is well displayed in the beautifully perfect neck already cited at Newark Castle, near St Monans (fig. 11). The strata through which this neck rises consist of shales, sandstones, thin coal, and encrinal limestones, dipping in a westerly direction at angles ranging from 25° to 60°. At the south end of the neck they are as sharply truncated as if by a fault. Elsewhere they are much jumbled, slender vein-like portions of the tuff being insinuated among the projecting portions. A large vertical bed of sandstone, 24 yards long by 7 yards broad, stands up as a sinuous reef on the east side of the vent (*s*, fig. 11). It is a portion of some of the surrounding strata, but is entirely surrounded with agglomerate, so far as can be seen at the surface. Here and there the shales have been excessively crumpled, and at the north end have been invaded by a vein of basalt which, where it runs through them, assumes the usual clay-like character. As shown in the drawing (fig. 11), the strata have been blown out, and their place has been occupied by a corresponding mass of volcanic agglomerate. They have undergone comparatively little alteration. In some places they have been hardened, but their usual texture and structure remain unaffected.

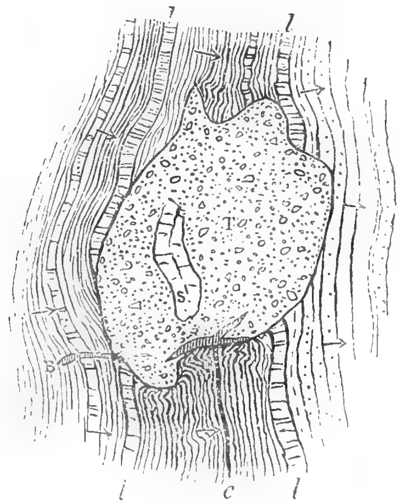

Fig. 11.—Plan of volcanic neck of agglomerate on beach near St Monans.

T, Neck of tuff enclosing a mass of sandstone (*s*), and piercing sandstones and shales with beds of limestone (*l*,*l*,), and a thin seam of coal (*c*); B, basalt "white trap" dyke. The arrows show the dip of the strata.

In other instances the boundary-line between the neck and the surrounding rocks is less sharply marked. Not infrequently the latter, as laid bare on beach-sections, protrude in tongues and irregular projections into the neck, while the tuff or agglomerate runs in veins and dykes, or fills up indentations in the boundary walls. This structure is illustrated by fig. 12, which represents a

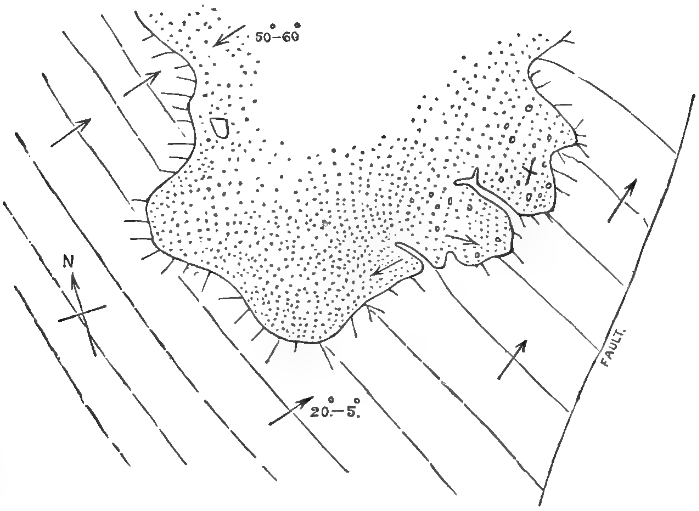

Fig. 12.—Ground-plan of Tuff-neck, shore east of Dunbar.

(The surrounding rocks are sandstones, which are much hardened round the vent in the zone marked by the short diverged lines. See "Geology of East Lothian," *Mem. Geol. Survey.*)

ground-plan of a neck in the East Lothian district. In some cases, as already stated, particularly in the east of Fife, injections of a kind of volcanic mudstone have filled up rents in the surrounding rocks, so as to look like true lava dykes or veins.

In the great majority of the shore-sections, a remarkable change of dip is observable among the strata round the edge of each vent. No matter what may be the normal dip of the locality, the beds are bent sharply down towards the wall of the neck, and are frequently placed on end. The structure (shown in figs. 6 and 8) is precisely the reverse of what might have been anticipated, and can hardly be due to the upward volcanic explosions. It is usually associated with considerable metamorphism in the disturbed strata. Shales are converted into porcellanite or various jaspery rocks, according to their composition. Sandstones pass into a distinct quartz-rock, with its characteristic lustrous fracture. It is common to find the vents surrounded by a ring of this altered sandstone, which from its hardness and vertical or highly inclined bedding, stands up prominently on the beach (as in fig. 12), and serves to mark the position of the necks from a distance.

I have not been able to find an altogether satisfactory explanation of the inward dip of the strata round the vents. Taking it in connection with the metamorphism, I am inclined to believe that it took place after the long-continued volcanic action which had hardened the rocks round the volcanic pipe had ceased, and as the result of some kind of subsidence within the vent.

The outpouring of so much tuff and lava as escaped from many of the volcanoes would doubtless often give rise to cavities underneath them, and on the decay of volcanic energy there might be a tendency in the solid or cavernous column filling up the funnel, to settle down by mere gravitation. So firmly, however, did much of it cohere to the sides of the pipe, that if it sank at all, it could hardly fail to drag down a portion of these sides. So general is this evidence of downward movement in all the volcanic districts of Scotland where the necks have been adequately exposed, that the structure may be suspected to be normal to all old volcanic vents. It has been observed among the shore-sections of the volcanoes of the Auckland district, New Zealand. Mr C. Heaphy, in an interesting paper upon that district, gives a drawing of a crater and lava-stream abutting on the edge of a cliff where the strata bend down towards the point of eruption, as in the numerous cases in Scotland.*

Evidence supplied by the Tuff-necks regarding Subœrial Volcanic Action.—From the stratigraphical data furnished by the Basin of the Firth of Forth, it is certain that this region, during a great part of the Carboniferous period, existed as a wide shallow lagoon, sometimes overspread with sea-water deep enough to allow of the growth of corals, crinoids, and brachiopods; at other times shoaled to such an extent with sand and mud as to be covered with wide jungles of a lepidodendroid and calamitoid vegetation. As volcanic action went on interruptedly during a vast section of that period, the vents must sometimes have been submarine, but may at other intervals have been subærial. Indeed, we may suppose that the same vent might begin as a subaqueous orifice and continue to eject volcanic materials, until as these rose above the level of the water, the vent became subærial. I have not been able to determine which were submarine vents; but some interesting evidence may be collected to show that many actually rose up as insular cones of tuff above the surrounding lagoon.

The structure of the tuff in many necks suggests subærial rather than subaqueous stratification. The way in which the stones, large and small, are grouped together in lenticular seams may be paralleled in the slopes of many a modern volcano. Another indication of this mode of origin is supplied by the traces of wood to be met with in the larger tuff-necks. The vents of Fife and Linlithgowshire contain these traces sometimes in great abundance. The specimens are always angular fragments, the largest I have observed being a portion of a stem about 2 feet long and 6 inches broad, in the neck below St Monans church. They are frequently encrusted with calcite. In a neck to the west of Largo Law I found many pieces with the glossy fracture and clear ligneous structure shown by sticks of well-made wood charcoal. In another neck at St Magdalens, near Linlithgow, the wood fragments occur as numerous

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* Quarterly Journ. Geol. Soc. 1860, p. 245.

black chips. So far as can be ascertained from the slices already prepared for the microscope, the wood is always coniferous. These woody fragments have not been found in the interstratified tuffs nor in the associated strata. They are specially characteristic of the necks. The trees from which they are derived grew, I believe, on the volcanic cones, which as dry insular spots would support a different vegetation from the club-mosses and reeds of the surrounding swamps. As the fragments occur in the tuffs which, on the grounds already stated, may be held to have been deposited within the crater, they seem to point to intervals of volcanic quiescence when the dormant or extinct craters were filled with a terrestrial flora, as Vesuvius was between the years 1500 and 1631, when no eruptions took place. Some of the cones, such as Largo Law, the Saline Hill, and the Binn of Burntisland, no doubt rose several hundred feet above the water. Clothed with dark pine woods, they must have formed a notable feature in the otherwise monotonous scenery of central Scotland during the Carboniferous period.

Relation of the visible Necks to the position of the original Volcanic Cones and the surrounding Sheets of Lava and Tuff.—From the facts above detailed, it is evident that in most cases the necks represent, as it were, the mere denuded stumps of the volcanoes. In some cases, indeed, denudation has not advanced so far as to lay bare the cones, which still consequently lie buried under subsequent accumulations. There must be many concealed cones of this kind in the region. In a few examples the progress of denudation has reached such a point that the cone can be partially made out amidst its surrounding masses of tuff. One of the most interesting of these is Largo Law, of which an outline has been given in fig. 2. The accompanying section (fig. 13) represents what appears to me to be the structure of this hill. There are two conjoined cones, each of which was probably successively the vent of the volcano. The southern and rather lower eminence, as already mentioned, is traversed by rib-like dykes of basalt, which point towards its top, where there is a bed of the same rock underlying a capping of tuff. On its eastern declivity lies the basalt *coulée,*

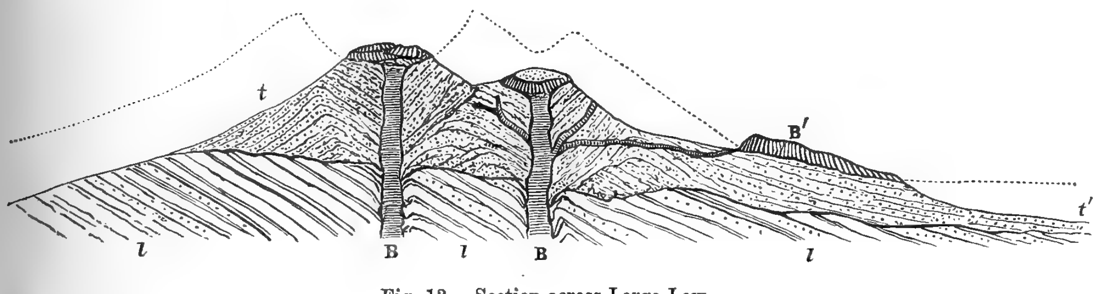

Fig. 13.—Section across Largo Law.

l, *l*, Lower Carboniferous strata ; *t*, Tuff of cones ; *t′*, Tuff of plain beyond the cones ; BB, Basalt ascending vents and sending out veins ; B′, Basalt which has probably flowed out at the surface. (See p. 467.) The dotted lines are suggestive of the original outline of the hill.

described on page 467. The higher cone is surmounted by a cake of basalt which, as I have above suggested, may have solidified at the bottom of the latest crater. Of course all trace of the crater has disappeared, but the general conical form of the volcanic mass remains. The upper dotted lines in the figure are inserted merely to indicate hypothetically how the volcano may originally have stood. On the west side, the sheets of tuff which were thrown out over the surrounding country have been almost entirely removed, but on the east and south they still cover an extensive area. (See fig. 1.)

Another excellent example of the connection between a conical neck and the surrounding masses of tuff and lava which proceeded from it is presented by the Binn of Burntisland, to which I have already alluded. A section across that eminence gives the geological structure represented in fig. 14. The dip of the rocks away from the volcanic pipe at this locality has been produced long after the volcanic phenomena had ceased. The arch here shown is really the prolongation and final disappearance of the great anticlinal fold of which the Pentland Hills and Arthur Seat form the axis on the opposite side of the Firth. But if we restore the rocks to a horizontal, or approximately horizontal position, we find the Binn of Burntisland rising among them in two or perhaps more necks, which doubtless mark one of the centres of volcanic activity in that district. A series of smaller neck-like eminences runs for two miles westward.

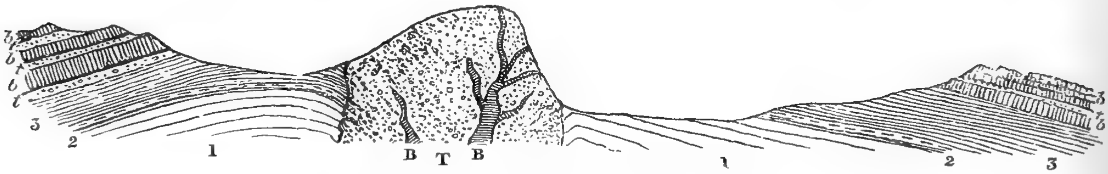

Fig. 14.—Section across the Binn of Burntisland.

1, Sandstones; 2, Limestone (Burdiehouse); 3, Shales, &c.; *b*, *b*, Interstratified basalts; *t*, *t*, Bedded tuff, &c.; T, Tuff of the great neck of Burntisland; B, Basalt veins.

Another remarkable instance of the connection of a volcanic pipe with the materials ejected from it over the surrounding country is furnished by Saline Hill in the west of Fife. That eminence rises to a height of 1178 feet above the sea, out of a band of tuff which can be traced across the country for fully three miles. Numerous sections in the water-courses show that this tuff is regularly interbedded in the Carboniferous Limestone series, so that the relative geological date of its eruption can be precisely fixed. On the south of Saline Hill, coal and ironstone, worked under the tuff, prove that this portion of the mass belongs to the general sheet of loose ashes and dust, extending outwards from the original cone over the lagoon in which the Carboniferous Limestone series of strata was being deposited. But the central portion of the hill is occupied by the volcanic pipe. A section across the eminence from north-west to south-east would probably show the structure represented in fig. 15. Immediately to the east of the Saline Hill lies another eminence, known as the Knock Hill, which marks the site of another eruptive vent. A coal-seam (the Little Parrot or Gas Coal) is worked along its southern base, and is found to plunge down steeply towards the volcanic rocks. This seam, however, is not the same as that worked under the Saline Hill, but lies some 600 feet below it. Probably the whole of the Knock Hill occupies the place of a former vent.

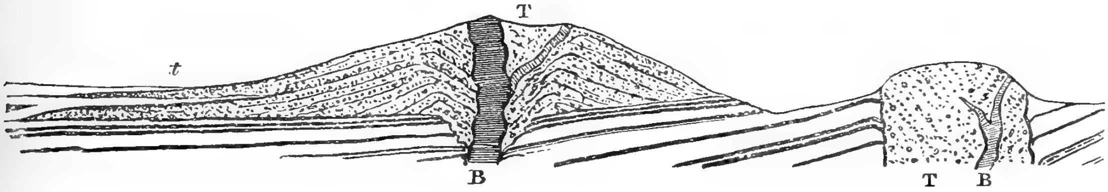

Fig. 15.—Section across the Saline Hills, Fife.

The thick parallel black lines mark the position of seams of coal and ironstone, some of which are worked under Saline Hill. T, Tuff of the necks; *t*, Tuff at a little distance from the cone, interstratified with the ordinary sedimentary beds; B, Basalt. The larger eminence is Saline Hill, the lower is Knock Hill.

Many additional examples might be cited of partially uncovered volcanic cones still surrounded by their ejectamenta. Probably in most cases the upper loose portion of a cone would be washed down as the general subsidence of the region brought it within reach of the water. Hence the crater would disappear, and only such rounded cones would remain as those which have been exposed once more to view by the removal of the overlying Carboniferous formations. The subjoined diagram (fig. 16) may serve to show the stages in the gradual re-emergence of these buried cones.

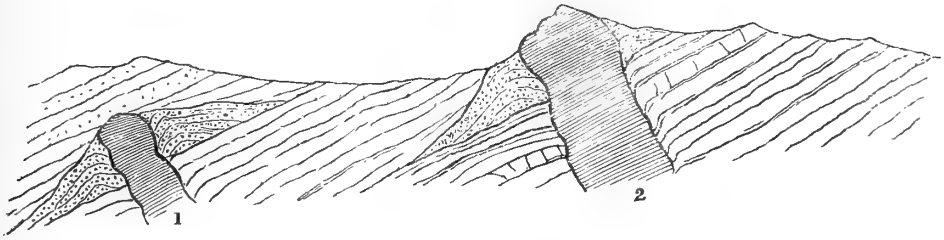

Fig. 16.—Diagram to illustrate how volcanic necks may be concealed and exposed.

1, Tuff and basalt neck, still buried under the succeeding sedimentary accumulations;
2, Tuff and basalt cone partially uncovered and denuded.

Final Stages of Volcanic Activity in the Tuff-necks.—After the explosions ceased by which the vents were opened and the cones of debris were heaped up, heated vapours would in many cases, as in modern volcanoes, continue for a long while to ascend in the vents. The experiments of DAUBRÉE on the effects of water and vapour upon silicates under great pressure and at a low red heat, have shown how great may be the lithological changes thereby superinduced. It is inconceivable, therefore, that the mass of tuff and lava lying deep within a volcanic vent, and thoroughly permeated with constantly ascending heated vapours, should escape some kind of change. I am inclined to attribute to this cause the frequent conversion of the sandstones round the walls of the vents into quartz-rock. The most remarkable example of metamorphism within the vent itself, which I have observed in the Basin of the Firth of Forth, occurs in the great vent of the Campsie Hills.* That remarkable volcanic orifice has been filled up with materials, some of which present the usual characters of coarse agglomerate, but with a more decidedly crystalline matrix. This crystalline texture increases here and there to such a degree that the rock assumes the aspect of some of the lavas of the district. Yet its original fragmental character is indicated not only by its gradual passage into unmistakable agglomerate, but still more by the occurrence in it of numerous blocks of sandstone more or less completely converted into quartzite. This local and unequal re-crystallization of the volcanic debris of the neck is the kind of metamorphism to be looked for as the result of the prolonged ascent of superheated steam under some pressure within the pipe of a volcano. I may add, that in this same neck numerous veins of a yellow or pink felsitic rock may be seen traversing the agglomerate, and extending also into the surrounding bedded porphyrite-lavas. The frequent highly silicated composition of the veins in the vents of the porphyrite regions is a remarkable and not very intelligible fact.

2. *Intrusive Sheets and Dykes.*

Throughout the Basin of the Firth of Forth, every division of the Carboniferous system has been invaded by intrusive sheets or dykes of crystalline igneous rocks. These masses may sometimes have been connected with the surface by vents or cracks up which a portion of the molten material rose. In most cases, however, they ought probably to be regarded as hypogene manifestations of volcanic action,—portions of lava which, unable to reach the surface, were forced between the bedding, joints, and faults of the strata. It will be shown in a later part of this Essay that they possess crystalline characters which serve to distinguish them from the superficial lava-streams or interbedded sheets.

General Characters.—The petrography of these rocks will be more particularly discussed in the second part of this paper. They consist almost entirely of rocks to which the names diabase, dolerite, and basalt may be applied. Occasionally they are of a felsitic nature. They include all the more crystalline and granitoid rocks of the region, though occasionally they present the ordinary close-grained black aspect of basalt. Their texture may be observed to bear some relation to

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* See Explanation to Sheet 31, "Geological Survey of Scotland," par. 21 (1878), mapped by Mr R. L. JACK.

their mass, so far at least as that where they occur in beds only two or three feet or yards in thickness, they are almost invariably closer-grained. A cellular or amygdaloidal texture is hardly to be observed among them, and never where they are largely crystalline or granitoid. Differences of texture, however, may often be observed within short distances in the same mass, and likewise considerable varieties in colour and composition. As a rule, the most finely crystalline portions are those along the junction with the stratified rocks, the most crystalline occurring in the central parts of the mass. A diminution in the size of the crystalline constituents may be traced not only at the base, but also at the top of a sheet, or at any intermediate portion which has come in contact with a large mass of the surrounding rock. Salisbury Crags may be cited as a good example; another, and in some respects better, illustration is supplied by the intrusive sheet at Hound Point (fig. 17), to the east of South Queensferry, where some layers of shale have been involved in the igneous rock, which becomes remarkably close-grained along the junction.* This change in texture and absence of cellular structure form a well-marked distinction between these sheets and those which have flowed out at the surface as true lava-streams.

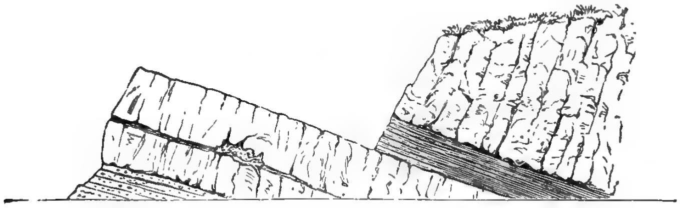

Fig. 17.—Intrusive sheets between shales and sandstones, Hound Point, Linlithgowshire.

Another characteristic of the intrusive sheets is the alteration they produce among the strata through which they have made their way, whether these lie above or below them. The strata are sometimes crumpled up in such a way as to indicate considerable pressure. They are occasionally broken into fragments, though this may have been due rather to the effects of gaseous explosions than to the actual protrusion of melted rock. But the most frequent change superinduced upon them is an induration which varies greatly in amount even along the edge of the same intrusive sheet. Sandstones are hardened into quartz-rock, breaking with a smooth clear glistening fracture. Shales pass into a kind of porcellante, jasper or Lydian-stone. Coals are converted into a soft sooty substance, sometimes into anthracite. These alterations, and the remarkable changes of texture experienced by the invading dolerites, will be again referred to in Part II.

Further evidence of the truly intrusive nature of these sheets is to be

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* See Hay Cunningham's "Essay," p. 66, and plate ix., and "Geol. Survey Memoir on Geology Edinburgh," p. 114.

found in the manner in which they catch up and completely enclose portions of the underlying or overlying strata. The well-known examples on Salisbury Crags (fig. 18) are paralleled by scores of other instances in different parts of the region. The subjoined woodcut (fig. 19) represents the way in which an intrusive sheet of a pale much altered rock involves shales in the Edinburgh district.


Fig. 18.—Intrusive dolerite sheet enclosing and sending threads into portions of shale, Salisbury Crags, Edinburgh.

Moreover, the sheets do not always remain on the same horizon; that is, between the same strata. They may be observed to steal across or break through the beds so as to lie successively between different layers. No more instructive example of this relation could be cited than that of the intrusive rock which has been laid open in the Dodhead Limestone Quarry, near Burntisland. As shown in the accompanying figure (fig. 20) this rock breaks through the limestone and then spreads out among the overlying shales, across which it passes obliquely. But when we trace the larger intrusive sheets this transgressive character is seen to be sometimes manifested on a great scale. Thus, along the important belt of intrusive rocks that runs from Kilsyth to Stirling, the Hurlet limestone lies

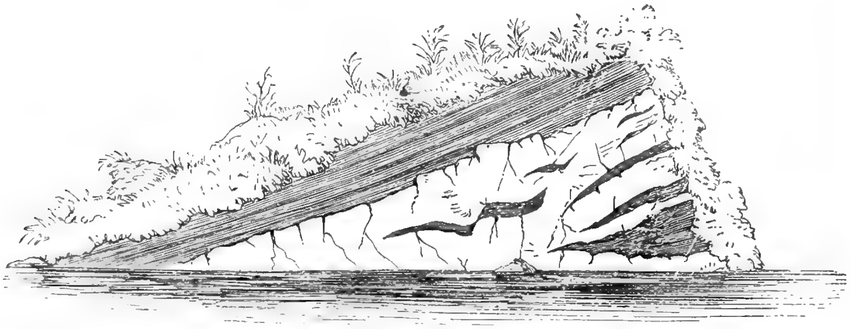
Fig. 19.—Intrusive sheet enveloping shales. Bed of Linhouse Water. "Geol. Survey Memoir of Edinburgh District," p. 115.

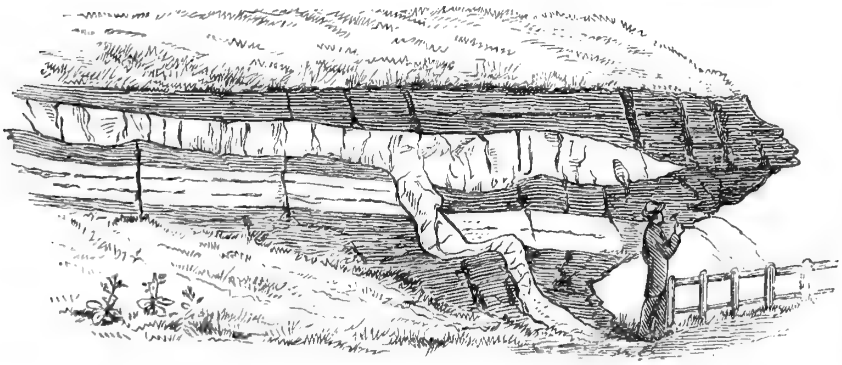
Fig. 20.—Intrusive sheet invading limestone and shale, Dodhead Quarry, near Burntisland.

in one place below, in another above, the invading mass, but in the intervening ground has been engulphed in it. Similar evidence of the widely separate horizons occupied by different parts of the same intrusive sheet is supplied at Kilsyth, where the intrusive sheet lies about 70 or 80 fathoms below the Index Limestone, while at Croy, in the same neighbourhood, it actually passes above that seam.*

The thickness of the intrusive sheets varies within tolerably wide limits. They here and there dwindle down to an inch or less in thickness, running away as threads from some thicker mass. But they more usually form masses of considerable depth. The rock of Salisbury Crags, for example, is fully 150 feet thick at its maximum. That of Corstorphine Hill is probably about 350 feet. The great sheet which runs among the lower limestones from Kilsyth by Denny to Stirling has been bored through to a depth of 276 feet, but as the bore started on the rock, and not on overlying strata, some addition may need to be made to that thickness.

Area and Horizons.—Taking first the area of surface occupied by intrusive sheets apart from their geological horizons, we observe that the Falkirk and Stirlingshire coal-field is girdled with a great ring of these sheets. Beginning at the Abbey Craig, near Stirling, we may trace this ring as a continuous belt of high ground from Stirling to the River Carron. Thence it splits up into minor masses in different portions of the Carboniferous system, and doubtless belonging to different periods of volcanic disturbances, but yet sweeping as a whole across the north-eastern part of the Clyde coal-field, and then circling round into Stirlingshire and Linlithgowshire. There are no visible masses to fill up the portion of the ring back to Abbey Craig. But through the high grounds of Linlithgowshire a number of minor intrusive sheets form an eastward prolongation of the ring, taking in the masses near Edinburgh, and then bending northwards into Fife. In the latter county the intrusive masses acquire their greatest development. A nearly continuous belt of them runs from the Cult Hill near Saline on the west, to near St Andrews on the east, a distance of about thirty-five miles. This remarkable band is connected with a less extensive one, which extends from Torryburn on the west, to near Kirkcaldy on the east. It is remarkable that to the east of the axis of the Pentland Hills hardly any trace is to be seen of intrusive sheets.

If now we examine the geological position of the strata invaded by these intrusive masses, we find that by far the larger proportion forms part of the Carboniferous Limestone series. The belt between Stirling and Kilsyth keeps among the lower parts of that series. On the same general horizon are the great sheets of dolerite which stretch through Fife in the chain of the Cult, Cleish, and Lomond Hills on the one side, and in the eminences from Torryburn to

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* Explanation of Sheet 31, "Geological Survey of Scotland," §§ 43 and 83.

Kinghorn on the other. In Linlithgowshire and Edinburghshire, as well as in the south of Fife, they traverse the Calciferous Sandstone groups. If the horizon of the sheets furnished any reliable clue to their age, it might be inferred that they were intruded during the earlier portion of the Carboniferous period. But on closer examination it will be observed, that the same intrusive mass sometimes extends from the lower into the upper parts of the Carboniferous groups. Thus, in the west of Linlithgowshire, a large protrusion which lies upon the upper limestones, crosses most of the Millstone Grit, and reaches up almost as high as the Coal-measures. Again, in Fife, to the east of Loch Leven, a spur of the great Lomond sheet crosses the Carboniferous limestone, disregards a large fault, and advances southward into the coal-field of Kinglassie. In Stirlingshire and Lanarkshire, numerous large dolerite sheets have invaded the Millstone Grit and Coal-measures, including even the upper red sandstones, which form the top of the Carboniferous system in this region.

Relation of the Intrusive Sheets to the Volcanic Centres.—Some light might be expected to be thrown on the age of the intrusive sheets by the manner in which they are related to the various centres of volcanic activity, but a satisfactory connection can hardly be established between them. Where the intrusive sheets reach their greatest development there are few, sometimes no trace of volcanic pipes, with their associated beds of tuff and streams of lava. On the other hand, in those tracts where volcanic orifices must have been active for long periods, intrusive sheets, when they occur at all, are commonly small and unimportant. In the case of a hill like Arthur Seat, where the lowest igneous rocks are intrusive sheets, and where the higher and larger mass consists of lavas and tuffs, erupted at the surface, we might speculate on the probability that the lower sheets of molten rock had been injected between the planes of the strata, either during some of the preliminary hypogene efforts, before direct communication had been established with the surface, or subsequently towards the close of the volcano's history, when that communication had become choked up. But in the case of the volcanic hills to the north of Burntisland, the intrusive sheets lie not below but above the interbedded lavas and tuffs, through which they come as irregularly as through ordinary sedimentary rocks. The most direct connection between volcanic pipes and large doleritic and basaltic sheets is to be seen in the east of Fife. To the north-east of Largo, for example, a plateau of this nature runs for a distance of four miles, with a breadth of about one mile. Round its margin are scattered upwards of a dozen small volcanic vents filled with tuff, and some of them partially with basalt. Its external characters exactly resemble those of many of the true intrusive sheets further west. But as no rock is found lying above it, it cannot certainly be affirmed to be itself an intrusive mass, though its internal structure, as revealed by the microscope, so entirely agrees with that of intrusive sheets, and differs from that of interbedded masses, that we may regard it as having been once covered by rocks under which it was injected. Since, however, isolated portions of columnar basalt occur in this and some of the neighbouring masses, we have probably to do with phenomena both of a hypogene and superficial character. These basalts may have flowed out at the surface from one or more of the surrounding vents, though the main sheets of dolerite were intrusive. This association of intrusive and interbedded masses round the same volcanic centre would be precisely analogous to that at Arthur Seat. The microscope furnishes a satisfactory means of discriminating between many of the intrusive and interbedded igneous rocks, as will be explained in the sequel.

Age of the Intrusive Sheets.—As the great epoch of volcanic activity in the Basin of the Firth of Forth extended from an early part of the Calciferous Sandstone period to near the close of the Carboniferous Limestone, it is probable that a large number of the intrusive sheets belong to some portion of that protracted series of volcanic eruptions. But some of them are certainly later than the latest known member of the Scottish Carboniferous system. These acquire a fresh interest and importance when viewed in connection with the evidence already given in this memoir regarding post-Carboniferous, or at least very late Carboniferous, volcanic action in Fife. For it is manifest that the phenomena were not confined to one small area. These late intrusive sheets cover a large area in Linlithgowshire and Lanarkshire. They reappear in Ayrshire, where the Coal-measures are likewise pierced with volcanic vents, and overspread with sheets of lava, tuff, and sandstone of Permian age. It is quite possible also, as I have already remarked, that some of the volcanic necks between the east of Fife and the heart of Ayrshire may belong to this late period. The later agglomerate of Arthur Seat has so exactly the character of some of the Permian necks of Ayrshire, that I suggested some years ago the probability of its being of the same age. More recently I have observed on Largo Law and others of the latest necks in the east of Fife, agglomerate precisely of the Arthur Seat type, which is coarser and redder, with more of the debris of the surrounding rocks, and less of the dirty-green diabasic matrix than the ordinary agglomerate of the older Carboniferous necks.

I have referred to the sheets of dolerite and basalt which in the east of Fife spread over considerable areas of the surface, and stand in evident relationship with the volcanic necks around them. In no material respect do they differ from the sheets which invade and overspread the upper Coal-measures in the great coal-field. In both cases they overlie the Carboniferous strata, and are not themselves covered by any later formation except glacial drift and other post-Tertiary deposits. All therefore that can be affirmed regarding them is that they are later than the youngest part of the Scottish Carboniferous system which they overspread unconformably. As a provisional arrangement, I would class them as probably of Permian date. That some, at least, are older than the Tertiary volcanic period is established by the fact, pointed out by me many years ago, that they are traversed by the great series of east-and-west Miocene dykes, though others in Stirlingshire may possibly be parts of an outflow from these dykes. For the reason, however, above given in regard to including the younger volcanic necks of Fife in this paper, I do not exclude these latest sheets.

Dykes.—Excluding the east-and-west Miocene dykes, there are comparatively few dykes in the Basin of the Forth save in connection with the volcanic necks, as already described. Among the red sandstones on which the city of Edinburgh is built, a number of dykes have been cut in draining, well-sinking, and other operations. Among the streams of the same neighbourhood an occasional dyke or vein may be seen traversing and involving the shales or sandstones. But the contact-phenomena do not call for any special remark in addition to what has been already said in reference to the intrusive sheets. Some of the curious features of internal structure presented by the dykes will be described in the Second Part of this Paper.

3. *Bedded Lavas and Tuffs.*

The minor cones in the region discharged in most cases only showers of tuff. Hence it is common to meet with beds of stratified tuff intercalated among the ordinary Carboniferous strata, without any other volcanic accompaniment. Numerous examples occur in Linlithgowshire and the western part of Edinburghshire, as well as in Fife. The tuff of these solitary beds is seldom coarse-grained. It usually consists of a fine dirty-green granular debris, derived from the trituration of the pyroxenic lavas of the period, and mixed with fragments of sandstone, shale, limestone, and other stratified rocks. It is often seamed with layers of ordinary sedimentary matter, probably indicating that its eruption did not occur at once, but was prolonged, with occasional pauses. The gradation of the upper part of the tuff into the overlying strata is often insensible, shewing that while the showers of tuff grew feebler, the usual sediment of the lagoon imperceptibly regained possession of the bottom.

From some of the larger or at least more close-set vents tuff continued to be thrown out for a long period, without the appearance of lava. The thick tuffs of Dunbar and North Berwick mark the earliest eruptions of the East Lothian district. The Saline vents threw out only tuff to a depth of several hundred feet. The numerous vents in the east of Fife likewise produced chiefly tuff, although lava certainly rose in many of them, if it did not actually escape at the surface in those wide sheets already noticed.

Lava-cones, answering to the solitary tuff-cones, do not appear to have existed. The lavas never occur without tuffs, except here and there where a number of successive flows lie piled one above another without visible trace of intercalated fragmentary layers (fig. 21). This, so far as can be observed, is the case in the Garlton Hills, though more numerous exposures might show thin interstratified tuff bands. In the Campsie Hills also a considerable thickness of superposed lava-beds occurs without the intervention of any prominent tuff layer. These, however, are exceptional cases in this region, and they belong, as I have already pointed out, to a type of volcanic action which attained a great development during the time of the Calciferous Sandstones in the western and south-eastern parts of Scotland.

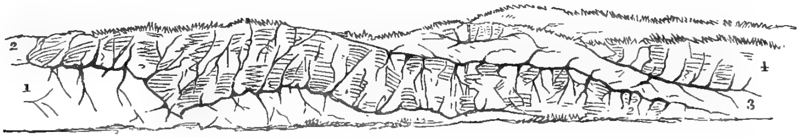

Fig. 21.—Section of four successive porphyrite lavas. East Linton, Haddingtonshire.

Leaving out of account the Campsie and East Lothian districts, in the other large accumulations of volcanic material, lavas and tuffs are interstratified with each other as well as with the ordinary sedimentary strata of the Carboniferous system. Perhaps the most complete and interesting example of this association is to be found on the coast between Burntisland and Kirkcaldy. The total thickness of rock in that section may be computed to be about 2000 feet. Of this amount it will probably be a fair estimate to say that the igneous materials constitute four-fifths or 1600 feet. The lavas vary in character from a black compact columnar basalt to a dirty green cellular or slaggy anamesite. They may average about 15 or 20 feet in thickness. Columnar and amorphous beds often succeed each other without any tuff. But along the junctions of the separate flows, layers of red clay, like the bole between the basalts of the Giant's Causeway, may frequently be noticed. The characteristic slaggy aspect of the upper parts of these ancient *coulées* is sometimes remarkably striking. It may be instructively contrasted with the close-grain of the upper and under margins of intrusive sheets.

Throughout the Basin of the Firth of Forth the basaltic lavas forming interbedded sheets, present external distinctions which serve to mark them off from the intrusive sheets. They are never so largely crystalline, nor spread out as such thick sheets; are frequently slaggy, amygdaloidal, fine-grained, and porphyritic; often decompose into a dull dirty-green fine-grained rock; and where they form a thick mass, are composed of different beds, of varying texture. The microscope confirms and extends these distinctions.

The number of intercalations of tuff in the admirable coast-section between Burntisland and Kinghorn is very great. Besides thicker well-marked bands, interstratified with the basalt beds, innumerable thin layers occur among the associated zones of sedimentary strata. The character of these tuff seams may be inferred from the following details of less than two feet of rock at Pettycur Point :—

Tuff,	1·5 inch.
Limestone,	0·2 „
Tuff,	0·5 „
Shale,	0·2 „
Tuff,	0·1 „
Shale and tuff,	1·0 „
Shale,	0·2 „
Limestone,	0·5 „
Shale full of volcanic dust,	3·5 „
Shaly limestone,	1·5 „
Laminated tuffaceous limestone,	2·0 „
Limestone in thin bands, with thin laminæ of tuff,	0·8 „
Granular tuff,	0·6 „
Argillaceous limestone, with diffused tuff,	0·9 „
Fine granular tuff,	0·7 „
Argillaceous limestone, with diffused tuff,	1·5 „
Laminated limestone,	0·1 „
Limestone, with parting of granular tuff in middle,	0·9 „
Tuffaceous shale,	2·0 „
Limestone,	0·4 „
Shaly tuff,	1·25 „
Laminated limestone,	0·1 „
Tuff,	1·2 „
	21·65 inches.

Such a section as this brings vividly before the mind a long-continued intermittent feeble volcanic action during pauses between successive outbursts of lava. In these intervals of quiescence the ordinary sediment of the lagoons accumulated and was mixed up with the debris, supplied by occasional showers of volcanic dust. Thin layers of sandstone, streaked with remains of the Carboniferous vegetation; beds of shale full of cyprid-cases, ganoid scales, and fragmentary ferns; thin beds of limestone, and bands of fireclay supporting seams of coal, are interleaved with strata of tuff and sheets of basalt. Now and then a sharp discharge of larger stones would take place, as in the case of the block described by me some years ago as having fallen and crushed down a still soft bed of coal.*

These volcanic eruptions, however, did not seriously interfere with the larger physical changes in progress over the whole region. Thus the depression

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* "Geol. Magazine," vol. i. p. 22.

which led to the spread of a marine and limestone-making fauna over much of central Scotland affected also this volcanic district. The limestones extended over the submerged lavas and tuffs, which, however, in spite of the subsidence, continued for some time to be poured forth until the volcanic activity at last ceased, and the whole area went down beneath a deep mass of Carboniferous deposits.

Numerous illustrations might be taken from Linlithgowshire showing a similar volcanic progress contemporary with ordinary quiet sedimentation. Two examples may suffice, one presenting intercalations of tuff, the other associated bands of lava. In fig. 22, we observe at the base a black shale (1) of the usual type. It is covered by a bed of nodular bluish grey tuff (2) containing black shale fragments. A second black shale (3) is succeeded by a second thin band of pale yellowish fine tuff (4). Black shale (5) again supervenes, containing rounded fragments of tuff, perhaps ejected lapilli, and passing up into a layer of tuff (6). It is evident that we have here a continuous deposit of black shale which was three times interrupted by showers of volcanic dust and stones. At the close of the third interruption, the deposition of the shale was renewed and continued, with sufficient slowness to permit of the segregation of thin seams and nodules of clay ironstone round the decomposing organic remains of the muddy bottom (7). A fourth volcanic interlude now took place, and the floor of the water was once more covered with tuff (8). But the old conditions of deposit were immediately afterwards resumed (9); the muddy bottom was abundantly peopled with ostracod crustaceans, while many fishes, whose coprolites have been left in the mud, haunted the locality. At last, however, a much more serious volcanic explosion took place. A coarse agglomeratic tuff (10), with blocks sometimes nearly a foot in diameter, was then thrown out, and overspread the lagoon.*

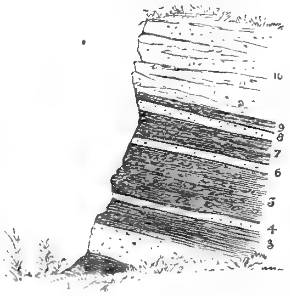

Fig. 22.—Section in old quarry, west of Wester Ochiltree, Linlithgowshire.—Calciferous sandstone series.

A second example from Linlithgowshire (fig. 23) brings before us a volcanic episode of another form in the history of the Carboniferous Limestone. At the bottom of the section a pale amygdaloidal, somewhat altered basalt-rock (A) marks the upper surface of one of the submarine lavas of that period. Directly over it comes a bed of limestone (B) fifteen feet thick, the lower layers of which are made up of a dense growth of the thin-stemmed coral *Lithostrotion irregulare.* The next stratum is a band of dark shale (C) about two feet thick, followed by about the same thickness of an impure limestone with shale seams (D). The conditions for coral and crinoid growth were evidently not favourable, for this argillaceous limestone

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* See "Geological Survey Memoir of Edinburgh," p. 45.

was eventually arrested first by the deposit of a dark mud, now to be seen in the form of three or four inches of a black pyritous shale (E), and next by the inroad of a large quantity of dark sandy mud and drift vegetation, which has been preserved as a sandy shale (F), containing *Calamites, Producti,* ganoid scales, and other traces of the life of the time. Finally, a great sheet of lava, represented by the uppermost amygdaloid (G), overspread the area, and sealed up these records of Palæozoic history.*

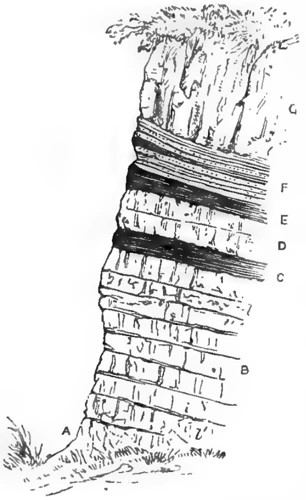

Fig. 23.—Section in Wardlaw Quarry, Linlithgowshire.

A final example may be cited of the regular alternation of lavas and tuffs with each other, and with ordinary sedimentary accumulations. The well-known Calton Hill of Edinburgh consists of the succession of rocks shown in the subjoined section (fig. 24). The great mass of the hill is made up of beds of porphyrite, representing true superficial lava-currents (Nos. 1, 5, 7, 9, 11, 13, 15). With these are intercalated bands of nodular tuff, and occasional seams of shale and sandstone, more or less charged with volcanic detritus (Nos. 2, 4, 6, 6′, 8, 10, 12, 14). The whole of this thoroughly volcanic series of rocks passes conformably under the Calciferous sandstones and shales shown at the right hand of the diagram.

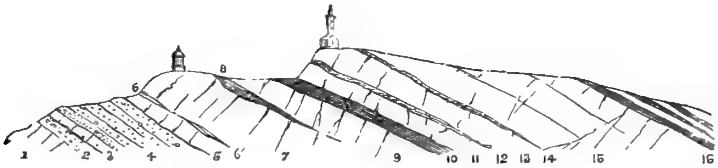

Fig. 24.—Section of Calton Hill, Edinburgh.

As the interstratified lavas and tuffs were laid down in sheets at the surface, they necessarily behave like the ordinary sedimentary strata, and have undergone with them the curvatures and fractures which have affected this region since Carboniferous times. Notwithstanding their volcanic nature, they can be traced and mapped precisely as if they had been limestones or sandstones. This perfect conformability with the associated stratified rocks is strikingly seen in the case of the great sheets of lava which, as I have already said, lie imbedded in the heart of the Borrowstounness coal-field. The overlying strata having been removed from their surface for some distance, and the ground having been broken by faults, these volcanic rocks might at first be taken for irregular intrusive bosses, but their true character is that shown in fig 25,

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* See "Geol. Surv. Mem., Geology of Edinburgh," p. 58.

where by a succession of faults, with a throw in the same direction, the upper basalts of Bonnytoun Hill are gradually brought down to the level of the sea.

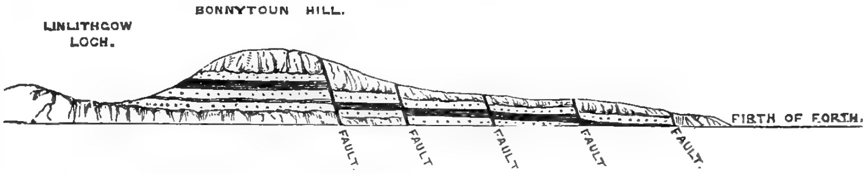

Fig. 25.—Section from Linlithgow Loch to the Firth of Forth.

Among the ancient volcanic phenomena of the Basin of the Firth of Forth, mention may, in conclusion, be made of the evidence for the former existence of thermal springs and saline sublimations or incrustations. Among the tuffs of North Berwick a fetid limestone has been quarried, which bears indications of having been deposited by springs, probably in connection with the volcanic action of the district. The rock has the peculiar carious wavy structure with minute mamillated interstices so common among sinters. It contains minute grains of iron-bisulphide and flakes of white kaolin, which probably represent decayed prisms or tufts of natrolite. The lower limestones of Bathgate furnish abundant laminæ of silica interleaved with calcareous matter, the whole probably due to the action of siliceous and calcareous springs. Some portions of the limestone are full of cellular spaces, lined with calcedony.* In a recent communication to this Society, I described the discovery of a saline water among the volcanic rocks to the west of Linlithgow. A bore was sunk to a depth of 420 feet without reaching the bottom of these rocks. The water that rose from it was found to contain as much as 140 grains of chloride of sodium in the gallon. It is not improbable, as I have suggested, that this salt was originally produced by incrustations on the Carboniferous lavas immediately after their eruption, as has happened so often in recent times at Vesuvius, and that it was then buried under the succeeding showers of tuff and streams of lava.†

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* "Geol. Survey Memoirs," *op. cit.* p. 49, *et seq.*

† "Proc. Roy. Soc. Edin." vol. ix. p. 367.

[PART II.

PART II.—PETROGRAPHY.

In the following section of this Memoir I propose to offer a sketch of the general results of a somewhat extended investigation of the characters revealed by the microscope in the various igneous rocks of the Basin of the Firth of Forth. A few of the more accessible rocks of the region have been microscopically examined and described by several observers, more especially by Mr ALLPORT, in whose interesting communication on British Carboniferous dolerites an account in particular is given of some of the igneous masses round Edinburgh.[*] But no attempt has yet been made to compare the minute structure of the volcanic rocks as a whole, and in connection with the history of volcanic action in the region, and to determine the leading types of composition and arrangement.

During the last twelve years I have devoted much time to the study of the microscopic characters of the crystalline rocks of Scotland. One portion of this inquiry has embraced an examination of the volcanic rocks described in the foregoing part of the present Memoir. I have had thin sections prepared of about 350 rocks from all parts of the region, illustrating every variety of composition and texture encountered by me in the field.[†] These sections present a most instructive picture of the original diversities of the volcanic masses, as well as of the alterations which their internal structure has subsequently undergone. The details which they furnish are full of interest, and I hope to publish them elsewhere. But a *resumé* of the chief results as yet arrived at in the course of the investigation may appropriately find a place as a sequel to the stratigraphical narrative in the preceding pages.

For the purpose of petrographical classification, as well as of stratigraphical detail, volcanic rocks may be arranged in two great leading subdivisions. I. The Crystalline, embracing all which have been erupted to the surface or intruded below in a molten condition; and II. The Fragmental, including all which have been thrown out in a fragmentary form. The former may be termed briefly the Lavas, and the latter the Tuffs.

I. THE CRYSTALLINE ROCKS OR LAVAS.

Looked at in their petrographical aspect as they occur among the Carboniferous formations of the Basin of the Firth of Forth, the Crystalline rocks or Lavas may be arranged into four chief groups—1st, Augite-felspar Rocks,

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[*] "Quart. Journ. Geol. Soc." vol. xxx. p. 529.

[†] These sections have been excellently prepared, in the petrographical laboratory of the Geological Survey of Scotland, by A. MACCONOCHIE and R. LUNN.

embracing all the basalts, anamesites, dolerites, and diabases, and thus by far the most abundant rocks in the region ; 2d, Olivine-augite-serpentine Rocks, hitherto observed only in two localities ; 3d, Felspar-magnetite Rocks, consisting of the "porphyrites," which played so important a part among the earlier eruptions of the Carboniferous period ; 4th, Felsitic Rocks, consisting of a few intrusive veins or dykes.

A. Augite-Felspar Rocks.

These crystalline masses play a chief part in the igneous phenomena of central Scotland. They present three recognisable types of structure, which however pass by insensible gradations into each other,—1st, The Diabases or granitoid type ; 2d, The Dolerites ; 3d, The Basalts.

I. The Diabases or Granitoid Type. (Plate XI. figs. 1 and 2).

1. *General External Characters.*—The rocks embraced in this group are thoroughly crystalline in structure, and usually remarkably coarse in texture. Some of their individual crystals measure occasionally an inch in length. They vary in colour partly with the tint and proportion of the felspar, and partly with the degree of alteration which they have undergone. Some varieties have a mottled pink hue, from the flesh-coloured felspar ; most are more or less distinctly greenish, from the decay of their magnesian silicates, and consequent diffusion of saponite, delessite, or other secondary product. They are never amygdaloidal, nor ever porphyritic, though here and there crystals considerably larger than those of the general mass may be observed. They always occur as intrusive masses, generally in sheets or amorphous bosses. They have manifestly been intruded at some depth from the surface among the Carboniferous rocks, and have never flowed above ground in lava-streams. Examples of this type are found among the hills to the west of Edinburgh. Lindsay's Craig near Kirkliston, Crossall Hill near Dalmeny, Muckraw near Torphichen, Auchensteary near Kilsyth, Croy, and the Carron Water above Denny, may be cited as localities where it is well displayed. But most of the coarsely crystalline intrusive sheets throughout the Lothians show the characters of this type more or less distinctly.

2. *Microscopic Characters.*—The structure is essentially crystalline. In many slices no trace of any ground mass can be made out between the separate crystals. Here and there a small proportion of a dull, minutely granular or microfelsitic substance may be detected between crossed Nicols. Most of the rocks, however, have been considerably altered, and many alteration-products appear between the still recognisable original crystals. It is possible that there may have been at first in some of the varieties a glassy or felsitic

magma, which is no longer recognisable. The chief component minerals are orthoclase, plagioclase, augite, titaniferous iron, and apatite. The general aspect of these rocks is represented in figs. 1 and 2, Plate XI.

The felspars usually constitute the main mass of the rock; but sometimes the augite is nearly equally abundant. Next in amount comes the iron. The proportion of the apatite varies within wide limits, being sometimes limited to infrequent stout prisms, at other times diffused in abundant minute needles.

The orthoclase, in the more typical examples, occurs to the almost total exclusion of any triclinic felspar. It is always somewhat kaolinised, but fresh portions may often be observed. It occurs macled in the Carlsbad form, and often shows its characteristic divergent herring-bone lineation from the plane of twinning. The alteration has resulted in the production of a finely granular substance, which between crossed Nicols appears dusted over with bright and coloured points, representing, doubtless, the silicic acid of the original felspar. The orthoclase prisms are frequently crowded with minute needles and larger hexagonal prisms of apatite, either promiscuously through the whole felspar, or directed from the exterior towards the centre, which may remain comparatively clear. In the more decomposed rocks the orthoclase has acquired a yellowish hue from diffused limonite.

The triclinic felspar, in the coarser and more typical varieties, is probably never labradorite. It differs from the characteristic labradorite of the dolerites and basalts in being less finely striated, and much more liable to decomposition. It often presents a milky appearance, which under a high power is resolved into a fine kaolinised substance. So generally is it decomposed, that though the external form of its prisms may remain distinctly marked off from the surrounding ingredients of the rock, no unaltered portions may remain, or if they occur they lie in small insular spaces amidst the surrounding granular kaolin. In proportion as the orthoclase diminishes, the triclinic felspar appears to increase. In the less largely crystalline varieties, however, it ceases to present itself as the milky, kaolinised albite-like mineral, but takes the usual water-clear well striated form of the labradorite, so characteristic of the typical dolerites and basalts of the region.

Augite is certainly the most conspicuous mineral under the microscope. This arises not only from its abundance in most of the rocks, but from its frequently and remarkably undecomposed aspect. Its freshness even in the presence of zeolites, "viridite," and other proofs of considerable alteration, is not a little singular. It is found in definite crystals of the usual eight-sided forms met with among igneous rocks; though the prisms are usually imperfect and are sometimes twinned, good cleavage angles of 87°·6′ are common. The augite may sometimes be observed enclosing prisms of the milky or finely granular triclinic felspars, which shoot through it and are wrapped round by it, showing that the augite has crystallised later than the felspar. As a rule the augite is tolerably free of extraneous substances. It is usually much cleaved and cracked, with occasional cavities either empty or filled with some decomposition product. Its most frequent endomorphs are needles and distinct hexagonal prisms of apatite. Thin rhomboidal plates of titaniferous iron are also occasionally to be noticed. The colour of the augite varies from a pale port-wine tint to a pale greenish brown in the fresh state. Here and there, even in the comparatively unchanged mineral, layers of a dirty green or brown decomposed substance, may be noticed in the internal cavities, or coating with a thin film the sides of the minute fissures. This is doubtless a product of decomposition of the augite itself. Every stage may be followed, from the first appearance of change until all trace of recognisable augite has disappeared, its place being taken by a mass of opaque brown and green amorphous earthy matter. In some varieties of rock the augite almost disappears. This may be observed in portions of the intrusive sheet west of Denny, where the rock consists mainly of orthoclase.

Olivine has not been certainly detected by me in any rocks of this type. Its presence may indeed be suspected from the serpentine so frequently to be noticed among the ingredients. But in no case have I ever observed any definite boundaries to the serpentine enclosures such as to indicate the outlines of olivine crystals. This is the more remarkable, as in many of the dolerites of the region which are quite as much altered as the rocks now under description, the olivine, though entirely serpentinised, still shows very distinctly the original outline of its crystals and granules. If any olivine ever existed in these coarsely crystalline intrusive rocks it must, I think, have been in very small quantity, and probably in granular indefinite aggregates rather than in homogeneous defined crystals.

Titaniferous iron is always present, and often in most interesting forms. Its fragmentary rhombohedra are scattered abundantly throughout the substance of the rock, sometimes enclosed in the augite and felspar, but usually independent. It frequently assumes the form of thin rhombohedral plates, which may now and then be observed to lie apart but parallel with each other, in obedience to original crystallographic force. There is a tendency not seldom to be observed, in these detached plates, to build themselves together into the framework of a crystal. Beautifully perfect skeleton rhombohedra of this kind may be seen in the rock of Crossall Hill, near Dalmeny (see fig. 26). Viewed by transmitted light, no structure can be made out in the individual crystals or lamellæ, though here and there they may be seen associated with the peculiar milky white *leucoxene* which sometimes, indeed, as DE LA VALLÉE POUSSIN and RENARD have shown in the case of the Belgian plutonic rocks, replaces the opaque iron in part or the whole of a crystalline face.

When, however, reflected light is employed, the velvet-black colour of the titaniferous iron, its semi-metallic lustre, small conchoidal fracture, and cleavage lines can be admirably seen. By this means also we ascertain that many apparently homogeneous masses of titaniferous iron have cavernous centres, more or less completely filled with pyrite. Amorphous particles of the same iron oxide also occur. Possibly these may conceal some magnetite. But the latter mineral has not been identified in any determinable crystalline forms among these rocks.


Fig. 26.—Skeleton rhombohedron of titaniferous iron, Crossall Hill, Dalmeny (magnified 20 diameters).

Apatite is probably never wholly absent, though its proportions vary within remarkably wide limits. In such very coarsely crystalline rocks as that of Crossall Hill, it occurs in colourless but somewhat dusty stout hexagonal prisms, sometimes 2·5 millimetres in diameter. It may there be seen shooting across from an augite into a felspar crystal without fracture, whence we may infer that at least in these portions of the rock there could have been but little motion of the mass at the time of crystallisation of the minerals. In other varieties of rock, such as that of Ratho, the apatite is crowded in the form of minute and perfectly clear hairs through the felspar.

In one or two examples quartz appears as an original constituent, in the form of small blebs. This is well shown in the case of the remarkable sheet of intrusive rock which has invaded the Carboniferous Limestone series in the valley of the Carron Water above Denny. The quartz appears there as occasional clear particles between the abundant kaolinised felspars, decayed titaniferous iron, and sparse, much altered augite. It contains numerous fluid cavities and small microlites. In most cases however, quartz, when present, is full of clouded impurities, contains no fluid cavities, and is aggregated in forms characteristic of this mineral as a secondary product.

As the rocks of the type now being described have all undergone more or less alteration, secondary products abound in them. Many of these form conspicuous features in the large veins and cavities to be seen in the quarry or natural section. Calcite, prehnite, pectolite, analcime, have long been known from these masses, and fine specimens, particularly of pectolite, have been obtained from Ratho and Corstorphine. Examined under the microscope, nearly every slice exhibits more or less of the amorphous brown and green earthy substance already referred to. This may be seen investing the augite and penetrating its fissures. But it also occurs diffused through rocks in which this mineral still remains fresh. It is not, therefore, produced by all varieties of augite, and is no doubt in a large number of instances due to the decay of some other minerals. Where it abounds the titaniferous ore is usually greatly oxidised, streaks and diffused grains or blotches of hæmatite, but more frequently of limonite, being abundant.

Serpentine or some serpentinous product is a frequent constituent of the rocks. It occurs of a pale apple-green colour ranging to dirty brownish green, is sometimes finely fibrous in tufted or plumose forms, and shows the characteristic aggregate polarization. In some rocks, that of Corstorphine for example, it occupies interspaces comparable in size to those of some of the original minerals. It might in such cases represent former olivine, but, as I have already stated, I have never detected it in rocks of this type retaining any outward crystalline form. It may sometimes be noticed in threads running through fissures, both of the augite and felspar. But the visible change of augite into serpentine is not common in any of the rocks which I have examined.

Besides the serpentine there occurs, sometimes in considerable quantity, a green translucent substance, occupying spaces between crystals, filling up cavities in the crystals themselves, and spreading in frequent filaments through minute fissures of this rock. In some instances it assumes beautifully fibrous, crested, and vermicular forms. Probably delessite and saponite are both included in these green alterations. According to the recent analyses of Dr Heddle, the green hydrous minerals of these volcanic rocks do not comprise chlorite, which he says is distinctively a mineral of the crystalline schists.

Plates of brown biotite appear in the more altered rocks, and minute prisms of hornblende occur under similar conditions. I have never observed any epidote. Pyrite is rarely altogether absent.

Calcedony in minute amygdules and strings is not infrequent among the more decayed varieties of rock, but crystalline quartz is the usual form in which the free silica has been deposited among the interstices of the rock. These quartz patches are distinguished from the original blebs of that mineral by the characters above specified, more particularly by the amount of impurities they contain, the absence of fluid cavities, and by the minutely flecked or aggregated structure which they present between crossed Nicols.

Arranged in the order of durability, the essential mineral constituents of these rocks would stand as follows:—The apatite remains singularly fresh, even in the midst of thoroughly kaolinized felspar. The quartz, where it occurs, is of course also unimpaired. Augite and titaniferous iron are about equally well preserved; where the one shows signs of alteration the other is usually also affected. The felspars have been almost invariably attacked, every stage being observable from the pellucid crystal to the dull granular kaolin. The green and brown decomposition products may represent in part minerals no longer recognisable.

From the description now given it will be seen that the largely crystalline intrusive sheets in the Basin of the Firth of Forth possess characters which do not admit of their being classed without some qualification in any established petrographical genus. From the dolerites they are marked off by the frequent preponderance of orthoclase and the presence of free quartz. From normal diabase they are also distinguished by their proportion of orthoclase, though undoubtedly they approach most closely to this rock, and I have retained this name as a generic designation for them. In many respects they remind one of augite-andesite. They show a similar mixture of monoclinic and triclinic felspars with augite, and a sparing quantity of free quartz. In judging of their relations to other rocks we must remember that they are always intrusive sheets, that in many cases they have caught up, and seem actually to have dissolved into their substance portions of the rocks through which they have been injected, and that as a fact they show very considerable differences of composition even within short spaces in the same mass. The proportions of the felspars, the relative abundance of the titaniferous iron and augite, the size and number of the cavities filled with alteration-products, all vary greatly from point to point.

Bearing these gradations in mind, we cannot be surprised to find that no line of demarcation can be drawn between the coarsely-crystalline orthoclase-bearing diabases and the dolerites to be immediately described. Varieties of rock occur which, according to the feature in their composition most kept in view, might be referred to either group.

II. The Dolerites. (Plate XI. Fig. 3.)

Under this title I have since the year 1867 classed the dark crystalline-granular augitic sheets by which the Carboniferous rocks of central Scotland have been invaded, and which were previously embraced under the term "greenstone."* Though the word "dolerite" has been restricted by German petrographers to rocks of Tertiary and post-Tertiary date, I was unable to discover any difference between those associated with the Carboniferous rocks and those which in the Inner Hebrides are certainly of Tertiary age. The opportunities for a comparison between them were many and favourable. I traced the probable connection of the numerous east and west "trap-dykes" which traverse Scotland, with the great Miocene lava-plateaux of the Inner Hebrides, and showed that these dykes, cutting as they do through all the known palæozoic and secondary rocks, including parts of the Tertiary volcanic sheets, and even across the latest faults of the country, were almost certainly of

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* Sheet 14, "Geological Survey, Scotland, Dec. 1868," and Explanation of same.

Tertiary age. They consist of undoubted and typical dolerite. They run across some of the great igneous sheets in the Coal-measures, and can there be admirably compared with the older rock. After examining them over a wide area in the field, and having had many slices cut from both series of rocks for microscopic investigation, I could never distinguish between them except by reference to their respective labels. Accordingly, I gave up this term greenstone in favour of dolerite, and this change has been adopted in all the subsequent publications of the Geological Survey in Scotland.

My friend, Professor ZIRKEL, who visited me in Ayrshire, and went over some of the evidence on the ground, came to the conclusion that no difference was to be made out by the microscope between the Carboniferous igneous rocks and those of Tertiary date.[*] Mr ALLPORT has come to the same conclusion.[†]

But while no recognisable distinction can be drawn between Carboniferous and Tertiary dolerites, I have been led to discover that a definite line of demarcation can be drawn between the intrusive dolerites and the augitic lavas which have been erupted at the surface. On a former page (*ante*, p. 481) I have referred to some of the broad external features of difference. But the microscope helps still further to discriminate them, and furnishes a valuable assistance in this respect to the labours of the geologist in the field. So reliable indeed are the microscopic tests, that I believe it is possible, in most cases at least, to affirm, even from the small portion of rock placed under the microscope, whether the parent mass consolidated beneath ground or at the surface.

Chemically there is probably, as a rule, little or no difference between the intrusive and interbedded sheets. Their differences lie in structure and texture, and point to the opposite conditions under which the rocks acquired solidity. While the intrusive sheets are conspicuously crystalline dolerites, the interbedded are essentially basalts of varying degrees of compactness. I would, therefore, restrict the term dolerite to the one, and basalt to the other petrographical group.

1. *General External Characters and Mode of Occurrence.*—In fresh undecayed specimens the texture of dolerite is markedly crystalline, passing into crystalline-granular. The component minerals can usually be distinguished either with the naked eye or a lens, the triclinic felspar appearing in clear glassy finely-striated prisms in the dark green or black base of augite and titaniferous iron. Hence the rock commonly presents a dark-grey speckled appearance. Where alteration has made progress, brown tints prevail on the outer crust, and the rock crumbles into a brown or even yellow sand, as its iron is converted into limonite.

An intrusive sheet is hardly ever amygdaloidal; when amygdules do

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[*] "*Mikroskopische Beschaffenheit der Mineralien und Gesteine*," 1873, p. 291.

[†] "Quart. Journ. Geol. Soc." *ut supra.*

appear they are small in size and limited in their range through the rock. It is distinguished by a peculiar uniformity of texture, seldom showing any large porphyritic crystals, such as frequently occur in the basalts. In some rare cases it may be columnar, but the columns are large and rude when compared with those of the basalts. The edges of a sheet where it approaches the contiguous strata present a much finer grain than the central portions. Small veins of this compact variety may occasionally be found penetrating the adjoining rocks, which are usually much indurated, both above and below intrusive sheets.

Rocks presenting these characters abound in this region; the great sheets traversing the Lanarkshire and Stirlingshire coal-field, those in the heart of Fife, and many of those in the West of Mid-Lothian may be taken as illustrations.

2. *Microscopic Characters.*—As above remarked, no sharp line can be drawn between these rocks and the diabases already described. The dolerites, however, seldom contain any orthoclase or any original quartz, and are never so coarse in texture. They show a remarkably crystalline structure under the microscope. In many varieties no distinct trace of any glassy ground-mass can be detected. In others this substance appears as a clear pale yellow or green limpid glass, crowded with dark trichites, and sometimes with minute green transparent microlites and needles of apatite.

The felspar is triclinic, and appears in clear colourless striated prisms sometimes half an inch long. It is probably labradorite; it can at least be easily distinguished from the milky translucent variety so common among the diabases. It sometimes contains minute glass enclosures, and is often studded with apatite needles, or crossed by stouter prisms of that mineral. Small dark grains, which may be titaniferous iron or magnetite, may likewise be observed. Not infrequently a remarkable finely fibrous, transparent, or translucent substance may be observed encrusting the felspar. It resembles the occurrence of a zeolite. Occasionally a detached portion of augite may be detected entirely enclosed in the clear felspar. But there can be no doubt that the latter mineral was the first to crystallise into definite prisms. Traces of orthoclase are comparatively infrequent, but a clear or a kaolinized prism twinning in the vertical axis may now and then be detected.

The augite occurs in large well-defined crystals, in irregular kernels, and rarely in minute granules. In most of the dolerites, particularly in the coarser varieties, it presents a fractured or flawed structure as in the diabases, and not uncommonly it might be supposed to have been penetrated across its figures by intrusive prisms of felspar. Beautiful examples of this relation of the two minerals may be noticed in the dolerites of the Falkirk and Slamannan coal-field. Examination with polarised light, however, shows that the apparent dislocations are at least in a vast majority of cases deceptive. What seem to be severed parts of one crystal with wedges of felspar between them, are then found to polarise on the same plane, and in short to belong to one undisturbed crystal which formed round and enclosed the already completed network of triclinic felspar prisms. Hence in one part of a slide we have one of these prisms completely enveloped in an augite crystal, while in an adjoining portion of the same preparation the augite seems to be completely enclosed within the felspar. There can be no doubt that, as above remarked, on the whole the felspar took crystalline form first. This is admirably shown in the contact-phenomena to which I shall afterwards refer. At the same time, there are occasionally indications that minute granules of augite in the original molten rock did form definite crystals before the crystallisation of the felspar was completed.

There is one distinctive feature between the mode of occurrence of the augite in the dolerites and in the interbedded anamesites and basalts which I have found to hold good, with few exceptions. While in the intrusive sheets the augite occurs either in well-marked crystals or in large crystalline irregularly-shaped portions, in the superficial lava-beds it is commonly present in abundant small granules and in sparse definite crystals. The granulated form has never been noticed by me in the dolerites, save in a few cases where the rock may have been almost superficial, or where it has been rapidly chilled by contact with the rocks through which it has been intruded. This point will be further described in the section treating of the interbedded basalt-rocks.

Apatite is present in most of the rocks, though extremely variable in amount. It assumes the form of fine needles and of stouter hexagonal prisms, but never attains the size it reaches in the diabases.

The opaque ferruginous mineral seems to be chiefly titaniferous iron. Distinct rhombohedral forms in thin lamellæ may often be noticed, and not infrequently with the same tendency to build themselves into crystallographic forms, which I have already noticed. But minute grains showing octohedral faces occasionally reveal the presence of magnetite.

Olivine is rarely recognisable, even as a serpentinous pseudomorph, and never in the freshly crystalline state. There is no greater contrast between the dolerites and the basalts than the part which this mineral plays in them respectively. In some dolerites small serpentine enclosures retain what are probably the outlines of former olivine grains and crystals. But these are small in size, and very vaguely characterised when contrasted with those which remain to be described in the basalt group.

Some of the more salient characters of the dolerites are represented in fig. 3, Plate XI., which shows the structure of a portion of the rock of Dalmahoy Hill, Edinburgh.

The alteration of the dolerites has produced results closely similar to those above described as occurring in the diabases. The triclinic felspar, though often singularly unchanged, may be detected passing into the granular kaolinised condition. The augite, as in the diabases, remains on the whole less affected than the felspar. It may, however, be observed with a surrounding border sometimes of an opaque black, sometimes of a dirty brown substance, which graduates inward into the still fresh augite. In other instances the external decomposed coating consists of serpentine, and strings of the same mineral may be traced along the fissures of the augite. The decomposition into serpentine may also be observed to have occasionally begun in the centre, while the surrounding part of the augite still remains tolerably fresh. Much diffused green matter, the so-called "viridite," may represent both olivine and augite. Leucoxene occurs under the same conditions as in the diabases. Hæmatite and limonite have often replaced the original iron oxides. Pyrite is almost always present in minute grains. Calcite, various zeolites, quartz, and calcedony fill up the pores and cavities of the rocks, and often run in veins through them.

Phenomena of Contact.—It is well known that an intrusive crystalline rock assumes a close texture along its junction with the rocks through which it has been thrust, and that these in turn commonly show more or less induration. I have examined a large number of microscopic sections taken both from the igneous and aqueous rocks, and will state here the general results of the investigation.

Tracing the variations of an intrusive dolerite outwards in the direction of the rocks which it has invaded, we perceive change first in the augite. The large crystals and kernels of that mineral grow smaller until they pass into a granulated form like that characteristic of basalts. The large plates and amorphous patches of titaniferous iron or magnetite give place to minute particles, which tend to group themselves into long club-shaped bodies. The labradorite continues but little affected, except that its prisms, though as defined, are not quite so large. The interstitial glassy ground-mass remains in much the same condition and relative amount as in the centre of the rock. In figs. 11 and 12 of Plate XII., I have drawn the structure of two interesting examples of contact phenomena.

Along the line of contact with a sandstone or other granular rock, the dolerite becomes exceedingly close-grained. Its felspar crystals are still quite distinct even up to the edge of the stratified rock, but are fewer in relative number, and still smaller in size, though an occasional prism two or three millimetres in length may occur. They retain also their sharpness of outline, and their comparative freedom from enclosures of any kind. They tend to range themselves parallel with the surface of the sandstone. The augite exists as a finely granular pale green substance, which might at first be taken for a glass, but it gives the characteristic action of augite with polarised light. It is intimately mixed through the clear glass of the ground-mass, which it far exceeds in quantity. The iron oxides now appear as a fine granular dust, which is frequently aggregated into the elongated club-shaped objects just referred to, as if round some inner pellucid or translucent microlite. In patches throughout the field, however, the oxides take the form of a geometrically perfect network of interlacing rods. This beautiful structure, described and figured by ZIRKEL and others,* is never to be seen in any of the dolerites, except close to the line of contact with the surrounding rocks. It occurs also in some of the dykes. (See Plate XII., fig. 12).

I have not succeeded in detecting any microlites in the sandstones at the edge of a dolerite sheet, though I have had many slices prepared for the purpose. The sandstones, so far as my observations go, do not offer any proofs of alteration capable of satisfactory elucidation by the microscope.

Where dolerite has invaded sandstone there is usually a tolerably sharp line of demarcation between the two rocks. It is seldom easy to procure a hand-specimen showing the actual contact, for the stone is apt to break along the junction-line. Where, however, the rock traversed by the igneous mass is argillaceous shale, we may find a thorough welding of the two substances into each other. In such cases the dolerite at the actual contact shows a still further degree of diminution in its component particles. It becomes a dark opaque rock, which in thin slices under the microscope is found to be formed of a mottled or curdled segregation of exceedingly minute black grains and hairs in a clear glassy matrix, in which the augite and felspar are not individualised. But even in this tachylite-like rock perfectly formed and very sharply defined crystals of triclinic felspar may be observed ranging themselves as usual parallel to the bounding surfaces of the rock. These characters are well seen in the contact of the intrusive sheet of dolerite with shale and sandstone at Hound Point, described on p. 475.

Another instructive example is furnished by the small threads which proceed from the dolerite of Salisbury Crags, and traverse enclosed fragments of shale. Some of these miniature dykes are not more than $\frac{1}{8}$th of an inch in diameter, and may therefore easily be included, together with part of the surrounding rock, in the field of the microscope. The dolerite in these ramifications assumes an exceedingly fine texture. The felspar is the only mineral distinctly formed into definite crystals. It occurs in prisms, sometimes $\frac{1}{5}$th of an inch long, and therefore readily recognisable by the naked eye. These prisms are perfectly shaped, contain abundant twin lamellæ, and show enclosures of the iron of the base. They had been already completely formed at the time of injection; for occasionally they may be observed projecting beyond the wall of

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* *Op. cit.* p. 273; Vogelsang's "Krystalliten."

the vein into the adjacent shale or sandstone, and they have ranged themselves parallel to the sides of the vein.* The black ground, from which these large well-defined crystals stand out prominently, consists of a devitrified glass, rendered dark by the multitude of its enclosed black opaque microlites. These are very minute grains and rudely feathered rods, with a tendency to group themselves here and there into forms like portions of the rhombohedral skeletons of titaniferous iron already described. Numerous green serpentinous granules may mark the position of the original augite. There is no trace of olivine.

So thoroughly fused and liquid has the dolerite been at the time of its injection, that little threads of it, less than $\frac{1}{100}$ of an inch in diameter, consisting of the same dark base, with well-defined felspars, may be seen isolated within the surrounding sedimentary rock. Minute grains and rounded portions of the latter may also be noticed in the marginal parts of the dolerite.

With regard to the change superinduced upon stratified rocks in the examples now under description, it is not easy to speak precisely, because the altered portions are completely enclosed within the mass of dolerite, and we cannot tell whence they were derived. They have acquired externally a percellanite aspect, and show numerous shining granules of quartz. Under the microscope this altered rock, which is pale grey or white, has a milky translucent finely granular or dusty base, reminding one of the base of a felsite. It contains thin layers of quartz pebbles, which are also scattered promiscuously through the more compact portions. I have not succeeded in detecting any microlites in this rock, save that here and there, close to its junction with the igneous threads and veins, it sometimes contains exceedingly minute cubes and irregular grains of a black opaque mineral. The quartz grains contain cavities, but are not clear, owing to the presence of many fine fissures and enclosed greenish matter. They may be seen projecting into the dolerite, which has moulded itself to them, and has sometimes detached and completely enveloped them.

It is evident that specimens taken from the edge of an intrusive sheet, where the rock has rapidly chilled and solidified, represent to us an earlier stage in

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* The infusibility of the felspar has been well shown in some recent experiments on the rocks of the neighbourhood of Edinburgh. At my request, Dr R. S. Marsden has subjected some of these rocks to fusion at the laboratory of the University of Edinburgh, and I have had microscopic sections prepared of the products obtained. The basalt of Lion's Haunch is peculiarly instructive. Its large labradorite crystals have resisted the intense white heat which, continued for four hours, has reduced the rest of the minerals to a perfect glass. We can thus well understand how large definite crystals of felspar should have appeared in dykes and veins while the rock was still thoroughly liquid. The glass obtained from the Lion's Haunch rock is of a honey-yellow, and contains translucent tufted microlites. The iron forms beautiful dendritic films in the cracks. Altogether, the glass presents a strong resemblance to the peculiar substance found in some of the tuffs of the vents to be afterwards described. I am at present engaged in a series of experiments on the fusion of volcanic rocks and artificial slags, and hope to communicate the results in a future paper to the Society.

the history of the whole mass than specimens taken from its central portions. In fact, a series of samples collected at short intervals from the outer contact to the inner mass shows, as it were, the successive stages in the consolidation of the molten rock.

From the observations just described, it appears that the triclinic felspars began to assume the shape of large definite crystals before any of the other minerals. These felspars already existed when the molten mass forced its way among the shales, for they can be seen lying with their long axes parallel to the surface of shale, precisely as, in the well known fluid structures, they behave round a large crystal imbedded in the heart of a rock. But most of the felspar remains still undividualised, together with the other constituents, in a dark glassy tachylitic magma. A few feet from where the consolidation was not so rapid, we perceive that the iron oxides grouped themselves into incipient crystalline forms and skeleton crystals; the felspar crystals formed abundantly, though small in size, and the augite was left as a finely granular green transparent substance. Still further towards the interior of the mass the normal character of the dolerite is gradually assumed.

One of the most constant kinds of alteration is that which affects dolerites and basalts where they have been intruded among carbonaceous shales or coals. A thin slice of the " white trap " from one of these junctions shows a dull white or pale yellowish granular translucent ground-mass, with a few small and decayed felspar prisms scattered through it. The absence of the usual green colouring matter and of the dark iron oxides is very marked under the microscope. The latter minerals seem to have been usually converted into siderite and limonite. The augite no doubt existed originally only in the minutely granulated form, but it cannot now be distinguished in the general kaolinised base.

III. The Basalts. (Plate XI. figs. 4 and 5.)

Under this title I include all those rocks of the augite-felspar series which have a compact or finely granular base, through which the component crystals of triclinic felspar (probably always labradorite) augite, olivine, and magnetite are crowded. This base consists partly of a clear or pale-brown glass groundmass, and partly of minutely granulated augite, and microlites probably of the felspar. It varies much in amount, sometimes almost disappearing; at other times occupying by far the largest bulk of the rock, and with only a few scattered crystals of the usual minerals, as in some of the most compact homogeneous basalts.

The more distinctly crystalline varieties are anamesites. The great majority are, however, true basalts. Though there is no essential distinction between these two varieties, the term anamesite may be retained as a convenient synonym for those coarser basalts, where the felspar in well-defined crystals plays a leading part.

1. *General External Characters and Mode of Occurrence.*—The basalts are broadly distinguished from the dolerites by their greater closeness of texture, darker colour, tendency to assume a regular columnar form, frequent slaggy and amygdaloidal character, and their association with tuffs as interbedded sheets in the Carboniferous system. The more compact varieties break with a splintery conchoidal fracture, are iron-black on the fresh surface, and appear to consist of a homogeneous dull substance, in which only here and there a few shining crystalline facettes can be seen. From this extreme graduations can be traced to a distinctly porphyritic texture, where the same dark base is crowded with crystals, among which prisms of labradorite, and augite and grains of olivine can be seen with the naked eye. The beautiful anamesite of Craiglockhart Hill, near Edinburgh, contains well-formed crystals of augite of the usual form, sometimes half an inch long, and crystals of serpentised olivine nearly as large.

The action of the weather, however, has greatly altered the external aspect of the basalts. In some cases, especially where columnar, they weather spheroidally, but instead of the thick coating of decayed shells so common among the dolerites, they may be found with merely a thin yellow crust, below which the rock appears fresh and black. Where they are amorphous, and especially where amygdaloidal, they decompose with a very characteristic dirty green aspect. Alternations of these two modes of weathering may be observed even in the same cliff, as at King Alexander's Crag, near Burntisland, where the bedding of the basalts can be descried even from a distance by means of the difference.

The basalts occur chiefly as interbedded sheets. With the exception of the porphyrites, all the lavas poured out at the surface in the Basin of the Firth of Forth during the Carboniferous period were basalts. The hills between Bathgate and Linlithgow, those of Burntisland in Fife, and of the neighbourhood of Edinburgh, offer good examples.

But the basalts assume also an intrusive form. So far as I have observed, they have never been thrust in great sheets among previously formed rocks; at least the rock so thrust has not consolidated in the form of basalt. They occur abundantly, however, as small veins and dykes in the neighbourhood of volcanic vents. They are as evidently due to the superficial operations of volcanic action, as the dolerites are to those of a more deep-seated kind.

2. *Microscopic Characters.*—Several distinct and very characteristic types of structure are revealed by the microscope among the basalt-rocks in the Basin of the Firth of Forth.

(1.) The more distinctly crystalline basalts or anamesites are well illustrated by the rocks of Craiglockhart Hill (see fig. 4, Plate XI.), and the Long Row, near Edinburgh. When a thin section of one of these rocks is placed under the microscope, the first mineral to arrest attention is the abundant and fresh triclinic felspar. It forms the predominating ingredient, occurring in prisms with perhaps an average thickness of ·002 inch, and a length of about ·03 to ·05 inch. Occasional large porphyritic crystals ·1 inch and upwards in length may be seen. This mineral has frequently enclosed globular grains of augite, and minute octohedra or irregular particles of magnetite. With a high power it may be seen to be sometimes full of fine clear glassy spicules. Beautiful fluid structure is shown by the arrangement of the thin felspar prisms round some of the larger included crystals.

The augite comes next in abundance to the felspar; indeed, it sometimes equals if it does not actually exceed it in quantity. This mineral is likewise well preserved. It occurs in two distinct forms:—1st, As minute granules without crystalline contours, but with the rounded drop-like form so characteristic of many basalts. This is the predominant condition. 2d, As large admirably definite prisms of the customary forms. These, as previously stated, are sometimes half an inch long, and can be seen projecting from some of the weathered faces of the rock at Craiglockhart Hill. The zonal growth structure is beautifully displayed by some of these augites. I have observed in a few instances, that though the external form is sharply defined by a continuous band of the mineral, the interior presents a granulated appearance, as if it consisted merely of a congeries of the augite granules. In the Craiglockhart rock some of the augites may be seen nearly unflawed, while others immediately adjacent are entirely granulated. The latter portions, however, polarise uniformly as a whole, and not according to the individual granules. Small crystals of felspar, grains of magnetite, and portions of the ground-mass may be observed between the granules, which are of larger size than the average of those in the ground-mass.

The olivine is almost always readily apparent. In some of the rocks it appears in crystals easily seen with the naked eye, some of them indeed, as at Craiglockhart, reaching a length of more than $\frac{1}{4}$ inch. I have never observed it in small grains like the augite. It occurs in two conditions—(*a*) In sharply defined crystals, with easily measurable angles. When in this form, it contains few or no endomorphs, and has been able to resist alteration better than in the other form. Some of its central portions may be found still clear, and showing the proper reaction with polarised light. But its borders are altered into a pale greyish or greenish white substance which also traverses the centre along fissures. This substance polarises like serpentine, and is doubtless a serpentinous alteration-product. (*b*) In the usual, somewhat rounded, ill-defined crystals and grains. In this condition the olivine is often full of magnetite grains and crystals, and is generally completely altered into a yellowish-green serpentinous substance. This is the ordinary mode of occurrence of the mineral.

The magnetite occurs in octohedra, averaging perhaps ·001 inch in diameter, also in many larger and irregular aggregations. Some of the latter, however, may be titaniferous iron. Apatite appears rarely in slender needles.

Between these recognisable minerals there lies a minutely granular base, which can be resolved by a high power chiefly into augite, with here and there traces of a dusty devitrified substance. But it cannot be called a glassy ground-mass. The proportion in which it occurs to the rest of the constituents is so small that the crystalline granular character of the rock remains conspicuous.

(2.) The true basalts vary greatly in details, but agree in the following general characters. The triclinic felspar occurs in minute prisms (perhaps on an average ·0005 of an inch thick and ·005 of an inch long) seldom in large porphyritic crystals. The augite appears in its two forms, but while the granulated condition is always present, the larger definitely shaped crystals are often absent. The olivine, always in serpentinous pseudomorphs retaining the rude contour of the original mineral, frequently lies in large porphyritic crystals. Magnetite forms a conspicuous feature, though its proportional amount is subject to great variations. The structure of the rock is always minutely granular, the granules consisting of augite; but between them, and in the wedge-shaped angles between the felspar prisms, a clear glass with pellucid spicules may sometimes be observed. (See fig. 5, Plate XI.)

The felspar is on the whole the predominant mineral, but this chief part is not infrequently taken by the granular augite. As in the dolerites, the felspar encloses globules of augite often less than ·0001 of an inch in diameter, also specks of magnetite. In fresh specimens it remains exceedingly clear and quite unchanged. It is always well striated. In some rocks its minute prisms are arranged in the most perfect fluid structure along the faces of the large olivines and augites. A good example of this arrangement is supplied by a very compact basalt on the shore to the west of Pettycur.

The augite granules average perhaps about ·001 of an inch in diameter. On applying a high power to their examination they are often seen to have imperfect crystalline outlines. That they are crystalline bodies, and not mere glass, is shown by their behaviour under polarised light. In some basalts—those of Kirkton, near Bathgate, for example—they appear as it were curdled together in irregular clots, with interspaces of a clear isotropic ground-mass. This tendency to segregation, however, has sometimes been in obedience to crystallographic force, for in the same district the granules are occasionally found in rings, the external outlines of which are rudely those of augite prisms, while the interior is occupied by a confused mass of augite granules, magnetite, and the general ground-mass of the rock. The colour of the granulated augite, under a low power, appears as a pale port-wine tint; but in thin slices, and with a high power, it is a pale brown or yellow, though the pink hue is not always lost even there. Perfect crystals of this mineral occur in some basalts; the most remarkable example in this respect with which I have met is from one of the dykes on the shore at St Monans, where, through a granular augitic base, regular prisms often twinned, are dispersed in great abundance, and admirably fresh. If minute petrographical subdivisions of the basalts were desirable, we might arrange in one series those where the felspar is greatly preponderant, and in another those where granular augite is the leading mineral.

The olivine varies much in quantity. In some basalts it appears only in occasional rare and small pieces; but usually it is discernible in every thin slice, and in some it forms a notable object even to the naked eye. It is always more or less converted into the usual green serpentinous substance. In certain basalts, especially in that of Mid Tartraven, Linlithgowshire, the olivine is occasionally so crowded with magnetite that this mineral forms by much the largest proportion of a crystal. The external form of the olivine remains distinct, however, and the altered serpentinous pseudomorph seems to bind the opaque octohedra together. In some of the Fife olivines the outer border is converted into a deep orange-yellow transparent strongly dichroic substance.

The magnetic iron appears in two forms. In the great majority of the basalts it assumes its usual form of minute octohedra, the shining triangular faces of which are well brought out by reflected light. But in some peculiar basalts the iron exists as minute thin lamellæ, which recall those of the diabases and coarse dolerites. From the angles obtained, however, and from the absence of the usual white porcelain-like accompaniment of titaniferous iron, I infer that these thin plates are magnetite. Basalts with this character occur at Pettycur in Fife, and also on the island of Inchkeith. Apatite is not recognisable.

The alteration of the basalts has always begun by the conversion of the olivine. Where much of this mineral is present, the decay of the rock produces the greenish hue so common among the interbedded sheets. The other minerals resist weathering for a long time, but the felspar is eventually kaolinised, the augite passes into a dark brown earthy substance, sometimes into serpentine, and the magnetite is oxidized into hæmatite, or more usually limonite.

It will be seen that in general arrangement of structure, these Carboniferous basalts of central Scotland exactly correspond with felspar basalts described by ZIRKEL from Germany, Faroe, Iceland, and the United States,* as well as with those of Tertiary age collected by him in Scotland. The endeavour to establish

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* See his *Basalt-Gesteine*, 1870, and "Report of Geol. Explor., 40th Parallel, Microscopical Petrography" (vol. vi.), p. 229. Washington, 1876.

a petrographical distinction between the older and younger basalts breaks down completely when the rocks of the Basin of the Firth of Forth are brought in evidence. In their behaviour in the field, and quite as much in their structure under the microscope, they cannot be discriminated from these of Tertiary date. The specimen from Strathblane which was described by ZIRKEL as a good example of an abundant type of true basalt, is an intrusive boss among the Carboniferous rocks, and is almost certainly of lower Carboniferous age.

IV. SERPENTINE-OLIVINE ROCKS.

Pikrite. (Plate XI. fig. 6.)

As an appendix to the normal dolerites and basalts, I insert here an account of a very remarkable and beautiful rock of rare occurrence in the Basin of the Firth of Forth. It is intimately associated with these rocks, and has evidently proceeded from some of the same vents. I know it as yet from only two localities—Blackburn, near Bathgate, and the island of Inchcolm. It appears to agree most closely with some of the rocks from the Fichtelgebirge, described by GÜMBEL under the name of "Pikrite."

1. *General External Characters and Mode of Occurrence.*—The variety from Blackburn occurs in that interesting belt of ground which runs southward through the Linlithgow and Bathgate Hills into the county of Mid-Lothian. This tract contains the records of a prolonged volcanic activity, during which lavas and tuffs were thrown out to a united depth of many hundred feet. The earliest eruptions began before the commencement of the deposition of the Carboniferous limestone series, and continued until the greater part of that series had been formed. As I have already stated, the lavas consist of basalts and amygdaloidal anamesites, the basalts being often singularly fresh, while the more coarsely crystalline rocks, especially where amygdaloidal, are often much decomposed. The volcanic ridge descends somewhat abruptly into the low grounds at its southern end. This arises apparently from several causes. A large fault with a downthrow to the south strikes eastward from the Bathgate coal-field, and skirts the southern base of the hills. The volcanic rocks are thus thrown down on the south side. Besides this, as the vents of eruption seem to have lain to the north, the accumulated sheets of lava and tuff no doubt thinned away in a southerly direction. Moreover, a vast amount of sandy and gravelly drift and of underlying boulder clay has been laid down over the lower grounds. That the volcanic rocks, however, continue southward is proved by numerous bores which have been sunk through the drifts in search of coal. They rise to the surface near the village of Blackburn, and after another interruption from the depth of glacial detritus are seen in the channel of the River Almond, whence they may be traced southwards for about two miles further. The sections in that stream, as well

as in the Briech Water, instructively show how rapidly the volcanic sheets diminish southwards. Of the vast mass of basalt and tuff intercalated between the lower limestones, most of that to the east of Bathgate has disappeared. It is the upper or later portion of the volcanic series, lying above the Main Limestone, which is prolonged southwards into Mid-Lothian, its position being indicated by the thin limestones between which it is intercalated.

At Blackburn one of the old lavas of a very peculiar kind has been quarried for many years as a material termed "lakestone," employed for the construction of the soles of ovens, owing to its capability of withstanding the effects of considerable heat. The rock is seen only at the quarry itself. It is there found to present a beautifully ice-worn upper surface, lying under a mass of stiff dark boulder-clay. In the channel of the Almond Water, immediately below the rock, some shaly sandstones and shales occur, with a thin seam of crinoidal limestone lying upon a few inches of coal. These strata dip towards the north-west at 25°, and the volcanic sheet has a similar inclination. It is evidently a bed intercalated in the limestone series. Its precise stratigraphical relations are made clear by a section in the Skolie Burn, less than two miles further south. A rock of a similar character, and quarried for the same purpose, is there exposed under a group of calcareous shales and thin limestone. Its upper part is in some places a fine slaggy amygdaloid. The strata lying directly upon it are of a peculiar green felspathic sandstone or shale, containing detached fragments of the amygdaloid, and likewise *Lingula* and other mollusca. It is clear that the rock is not an intrusive sheet, but is a true lava-bed, which was erupted and solidified at the surface during the accumulation of the older part of the Carboniferous Limestone series of West Lothian.

I am thus particular regarding the geological relations of this rock, because it stands at present as a nearly unique example of a very interesting variety of these Carboniferous lavas, and likewise offers a striking petrographical difference between the upper and under part of the same bed, such as I have not been able to discover anywhere else.

The rock is best displayed at the Blackburn Quarry. Looked at from a short distance, it appears to be one of the rudely jointed, somewhat decomposed brown or dirty-green doleritic or diabasic rocks of the district, with a tendency to weather out into spheroids. Examined more closely, the upper portion is seen to bear out this first impression, though evidently to present more decided traces of serpentisation than is usually to be observed. A specimen taken from the lower body of the stone would be termed a highly serpentinous diabase, nearly approaching a serpentine in outward aspect. Veins of serpentine and chrysotile, sometimes six inches thick and often streaked with calcite, run in vertical divisions through the whole rock. There is no line of demarcation to be drawn between the higher and lower parts of the rock. They cannot indeed be discriminated except by actual fracture and inspection, the whole mass appearing as one and indivisible. The upper part is too hard to be worked with profit, and is therefore thrown aside, but the workmen cannot fix any line below which the stone becomes valuable, except by the ease with which it yields to their tools.

A few hand-specimens, selected from various parts of the upper harder band, give the following characters:—Finely crystalline base of a dirty, blackish green colour, and a tolerably homogeneous but dull texture, showing many ill-defined greenish white points, apparently of decayed felspar, with minute facettes, some of which are pyrite; fracture, splintery; hardness, 3 to 4.

The variety from Inchcolm was brought to my notice by one of my students in the University, Mr Ernest Ady, who landing on the island, and being struck with the external aspect of the rock, took specimens, and sliced them for the microscope. It occurs in beds, under which lie some hardened sandstone, limestone, and shale. It seems to be an intrusive mass, as are those of the adjacent islands and the neighbouring coast of Fife. It is rather coarsely crystalline-granular. Even to the naked eye its honey-yellow grains of olivine, dark glancing crystals of augite, occasional plates of glistening brown biotite, and serpentinous interstitial matter, are quite apparent. But under the microscope it becomes an object of surpassing beauty.

2. *Microscopic Characters.*—The lower portion of the Blackburn rock consists chiefly of serpentine. This mineral occurs in (1) irregular patches, the edges of which are sometimes sharply defined against the other ingredients, while elsewhere they seem entangled among the latter; (2) in more definite forms, which are almost certainly those of former olivine; (3) in tufts and fibrous streaks; and (4) in veins of true chrysotile. Between the abundant portions of serpentine traces of a pale mineral full of serpentinous veins, which behaves like olivine in polarised light, are probably the last recognisable remnants of that mineral, which at first appears to have constituted the main part of the rock. Large, much-flawed crystals of a pale brown to claret coloured mineral are scattered through the serpentine, and are enclosed in the less altered olivine. These answer to augite in general behaviour with polarised light, but I have been unable to obtain any satisfactory cleavage angles. Numerous needles and fine prisms of apatite are crowded into some parts of the rock. Abundant iron black particles of titaniferous iron or magnetite occur, and a little pyrites. A few prisms of triclinic felspar also occur. There is no distinct ground-mass separate from the general base of serpentine.

The upper portion of the Blackburn rock presents a marked contrast in its minute structure. It contains among its constituents a feeble quantity of a distinct glass which occurs occasionally in large interspaces, and then shows a dusty character, resolvable with a high power into exceedingly minute dark globules.

The most abundant mineral is a colourless and tolerably fresh triclinic felspar. Next in amount is a pale yellowish transparent mineral in very small prisms, which seems to be augite, but of an unusual form. Some of these prisms, not exceeding ·0005 of an inch in diameter, may be seen enclosed in the altered olivine. The latter mineral can be recognised in the form of crystals, from about ·03 to ·10 of an inch in length, completely serpentinised. They consist mainly of a pale delicate apple-green clouded and fibrous substance, which is bordered and traversed by strings of a bright grass green, sometimes of rich yellowish brown. But these olivines occur in much smaller quantity than in the lower part of the rock. Titaniferous iron or magnetite likewise appears as in that lower part, but also in less abundance. Apatite may be detected occasionally. (See fig. 6, Plate XI.)

Without at present entering further into the detailed structure of this beautiful and interesting rock, the facts just stated show that in the lower half there is a preponderance of the heavy olivine, augite, and iron, while in the upper half the lighter felspar predominates. As I have said, it is quite impossible to draw any line between the two portions of the rock thus differently constituted. It is one indivisible mass, in which the lower part, a serpentine (representing olivine), shades up into the higher part, rich in felspar. In this case there has evidently been a separation of the ingredients according to their respective gravities, during the period when the mass was still in a molten condition, as Scrope pointed out in modern lavas. The fluidity of the rock must have been such as to allow of this segregation even after the lava had moved some way along the surface.

The Inchcolm rock is considerably fresher than that of Blackburn. Examined under the microscope, it is seen to be by far the most beautiful rock in the Basin of the Firth of Forth. The olivine, its most abundant mineral, is still in large measure quite undecomposed, though frequently presenting the usual external crust and transverse wavy threads of green serpentine. Large pieces of fresh olivine give the characteristic reaction with polarised light. Next in quantity comes the augite, which is likewise singularly fresh. It has in thin slices a pale claret colour, and gives cleavage angles of 87° and 93°. It occurs in large well-defined prisms of the usual forms, often enclosing grains and crystals of olivine. A milky felspar, full of fissures, filled with decomposition products, but still showing traces of twin lamellation, occupies a very subordinate place in the rock. Long scales of rich brown biotite occur here and there; also a few plates and grains of probably titaniferous iron. One of the most conspicuous ingredients is a rich emerald-green to grass-green product of decomposition, which fills up interstices, and running in veins and irregular streaks or tufts through the rock, gives a singularly bright tone to the field of the microscope. Other pale or colourless aggregates, sometimes distinctly fibrous, likewise occur. These various decomposition products give between crossed Nicols sometimes the reaction of serpentine, sometimes the pale milky blue tint and aggregate polarisation so often found in chlorite. Zeolitic fibrous tufts occur in some of the cavities. I have not observed any apatite.

B. Felspar-Magnetite Rocks.

THE PORPHYRITES. (Plate XII. figs. 7 and 8.)

Under this title I provisionally group those Carboniferous volcanic rocks which in the Basin of the Firth of Forth have been mapped as "felstones," "porphyrites," and "claystones." They present very great varieties of external aspect, but possess certain common characters which suffice to enable the field-geologist to distinguish them from the basalt series. Occupying a definite place in the Carboniferous system in Scotland, they belong entirely to the great volcanic epoch at the beginning of the Carboniferous period. They form the thick-terraced masses which range through the north of Ayrshire, Renfrewshire, and Dumbartonshire to the Forth at Stirling. They partially appear at Edinburgh, in the Calton Hill and Arthur Seat, but on a much more extended scale in the Garlton Hills of Haddingtonshire. Similar rocks in Berwickshire, Roxburgh, and Dumfries spread over wide areas at the base of the Calciferous Sandstones. They are thus the oldest and most generally distributed of the volcanic rocks associated with the Carboniferous system in Scotland. In most essential characters they agree with the lavas so copiously erupted in central Scotland during the time of the Lower Old Red Sandstone, with which in another memoir I shall again discuss them. They thus belong essentially to an older as well as a more vigorous volcanic type than the basalts. Even the thickest and most extensive series of basalt eruptions, such as those of the Burntisland and Linlithgowshire districts, are of trifling amount when compared with the enormous sheets of bedded porphyrite in the Campsie and Ayrshire Hills.

The porphyrites always occur as contemporaneous or interbedded sheets, save in those comparatively infrequent cases where they have filled up the volcanic funnels, and now appear in necks.

1. *General External Characters.*—A "porphyrite" is marked by a dull close-grained porphyry base, through which are usually scattered crystals of a triclinic, less commonly an orthoclase, felspar. The base is usually of some shade of red or brown, varying from a dark chocolate or purple tint to pale yellow or nearly white, greenish and bluish shades being less common. It is frequently amygdaloidal. As a rule, the porphyrites are somewhat altered, fresh specimens being in many cases unobtainable, or only with much difficulty. The weather-

ing has particularly attacked the iron oxide in the rocks, hence the frequent red, brown, and yellow tints.

An important feature of the porphyrites as compared with the basalts is their comparative lightness. Their average specific gravity is about 2·6 to 2·7, while that of the basalts is about 2·9, a difference which is appreciable even when specimens are held in the hand. Some intermediate varieties, however, helping to connect the porphyrites with the basalts, are not always easily distinguished by external tests.

2. *Microscopic Characters.*—The distinguishing mark of the porphyrites under the microscope is the character of their ground-mass. It appears as a clear, colourless substance through which vaguely defined prisms of triclinic felspar are crowded. Between crossed Nicols it presents a characteristic mottled structure, the light and dark parts shading off insensibly into each other. As the slide is rotated the mottling wanders over it, every portion becoming successively light and dark (see Plate XII. figs. 7 and 8). This continues to be the case even with a high power. In a very few cases only have I noticed small interspaces which remained persistently dark. Colourless hairs or fine rods are not infrequent; and occasionally minute pale yellow or nearly colourless globules, which polarise like the globular augite of the basalts, may be observed.

This clear anisotropic ground-mass can scarcely be anything else than a felspar. It blends so insensibly with the felspar prisms, that where the defined forms of these prisms cease it is impossible to separate their substance from the surrounding mass. This is the case with most of the Garlton Hill porphyrites. In some cases the prisms are well striated, and stand out more definitely. I have attempted to delineate the structure in the drawings above referred to.

The felspars chiefly occur in these vaguely outlined forms. But in many porphyrites they appear also as large porphyritic crystals with exceedingly sharply marked boundaries. In the majority of cases they are triclinic, and probably labradorite. Now and then clear twins of orthoclase are to be observed. Among the Garlton Hills the larger felspars are occasionally crowded with enclosures, sometimes promiscuously diffused through the crystal, at other times in lines along the planes of twinning. The most abundant enclosures are minute globules of augite, not infrequently elongated into rod-like bodies. In one or two cases I have noticed numerous perfectly black opaque globules. These may be augite crowded with magnetite dust.

Taking the clear ground-mass as felspar, and including with it the recognisable felspar crystals, we find that perhaps about nine-tenths of the substance of one of the most typical porphyrites is felspathic. Next in abundance is magnetite, which occurs in recognisable octohedra, not infrequently imperfect, and in irregular shred-like particles. Its crystals are often extremely minute; in some of the rocks of the Garlton Hills they are on an average less than ·001 of an inch in diameter. In these microscopic grains, however, we can easily see with reflected light the glancing triangular faces of the octohedra, and the sub-conchoidal fracture of the broken grains.

Augite is frequently, but not always, present. When recognisable, its most common form is that of minute globules, like those of the basalts, but of still smaller dimensions, enclosed in the felspars and in the clear ground-mass. Larger irregularly defined fragments, of a pale yellow tint in thick sections, which polarise like the augite globules, are probably also augite.

At the base of the lavas of the Garlton Hills certain rocks occur which present the same peculiar anisotropic ground-mass, but in much smaller quantity. The triclinic felspars are numerous, fresh, and well striated. Augite abounds in large crystals, as well as in smaller globular forms. Magnetite or titaniferous iron appears, but has commonly suffered oxidation. Pseudomorphs of serpentine and black ferruginous opaque matter replacing olivine (?) likewise occur. These rocks evidently form a connecting group between the anamesites and porphyrites.

The most characteristic Carboniferous porphyrites in the Basin of the Firth of Forth are those of East Lothian. They have been laid open in numerous quarries, as well as natural sections, on the Garlton Hills. The Calton Hill and Arthur Seat porphyrites are much decayed, but still show the characteristic ground-mass. The Campsie Fells contain many varieties of porphyrite, but these lie chiefly beyond the region embraced by the present Memoir.

In the progress of alteration the porphyrites undergo some characteristic changes. Their felspar suffers the usual kaolinisation. Their ferruginous constituent is oxidised into hæmatite, but more usually limonite, and they consequently weather into reddish-brown and yellow clays.

C. Felspar (Orthoclase) Rocks.

The Felsites. (Plate XII. fig. 9.)

Very few rocks of this class are included among the Carboniferous volcanic masses of the Basin of the Firth of Forth. Some examples occur among the necks of the Campsie Fells, and in the western neck on the shore at Largo.

1. *General External Characters and Modes of Occurrence.*—Under the term felsites, I group certain rocks varying in colour from a pale grey through shades of yellow to a deep red, usually compact in texture; in fresh fracture sometimes quite flinty, but mostly decayed, and presenting a more or less kaolinised

granular aspect; seldom porphyritic, but generally containing distinct blebs of quartz readily perceptible by the naked eye. They are all intrusive masses, and are confined to the necks or their vicinity. They occur as veins or dykes, sometimes in large neck-like masses.

2. *Microscopic Characters.*—Under the microscope these rocks show a characteristic finely granular felsitic ground-mass, through which are scattered grains or irregular pieces of quartz and crystals of orthoclase (see Plate XII. fig. 9). One of the most interesting varieties is that already referred to as occurring in veins, together with basalts, in the vent on the shore to the west of Largo. It is exceedingly flinty in texture, and looks so like altered shale that I at first regarded it as such. Its extreme hardness causes it to stand out prominently on the beach, where its enduring surface acquires in places a kind of polish from the friction of sand particles across it. Seen with a low power under the microscope, it shows a curious reticulated structure, which, in some respects resembling the normal structure of perlite, is marked by numerous narrow bands running through the rock and often intersecting each other. These bands differ from the rest of the ground-mass in being clearer and less thickly granular. In the interspaces between them the ground-mass thickens into cloudy patches with traces of a fluid structure of the perlitic kind. The orthoclase crystals and quartz, however, are found indiscriminately in the bands and in the interspaces or crossing from the one to the other. The orthoclase occurs in Carlsbad twins, averaging from $\frac{1}{50}$ to $\frac{1}{100}$ of an inch in length. The quartz is not definitely crystallised, but has taken the form of rounded blebs, sometimes with the drop-like form so often to be noticed in felsites. Its granules are distinctly visible to the naked eye, and are crowded thickly through the rock. They abound in cavities.

An interesting feature in this rock is its occurrence in one of the necks of the East of Fife where, with this exception, basalt is the only form of lava now to be seen. Throughout the great plateau of Lower Carboniferous porphyrites, extending from the Campsie Fells into Ayrshire, large bosses as well as veins of a yellow quartz-felsite are not uncommon. Yet no rock of this kind seem ever to have been erupted to the surface. Again, in the Lower Old Red Sandstones, while the outflows of lavas are thoroughly basic porphyrites, large intrusions of siliceous felsites have taken place at and round the necks, but never at the surface. At the Pentland Hills, however, during Lower Old Red Sandstone times, great showers of felsitic tuff were ejected. It would appear that, even at volcanoes giving out basic lavas and tuff, there has frequently been an uprise of extremely acid lavas in and around the vents.

II. THE FRAGMENTAL ROCKS OR TUFFS.

(Plate XII. fig. 10.)

From the nature of their origin the fragmental volcanic products cannot, like the crystalline rocks, be grouped into very definite petrographical subdivisions. They are not chemical mixtures, but mere mechanical aggregates, liable to constant variation in the characters and proportions of their constituents. Thus on the large scale we may encounter one of these masses presenting the greatest contrast in the composition even of two adjacent portions; and even when examined with the microscope, similar extreme diversity and variety may be traced.

1. *General External Characters and Modes of Occurrence.*—In the first place, it is to be observed that the fragmental rocks have two distinct modes of occurrence, in each of which they present special petrographical characters. They occur (*a*) filling up volcanic vents, and (*b*) interstratified with bedded lavas or with strata of an ordinary sedimentary kind.

(*a*) In Volcanic Vents.—By far the coarsest and most tumultuously assorted varieties occur in this position. Large subangular or somewhat rounded blocks of sandstone, limestone, or other stratified rock, according to the nature of the surrounding strata, are commingled with abundant blocks of dolerite, basalt, or some other variety of igneous rock in an earthy and gravelly paste of the same materials still further comminuted. These *agglomerates* are for the most part quite unstratified, though sometimes traces of a rude bedding may be discerned among them, the layers standing on end or at high angles in the manner already described (*ante*, p. 463). The agglomerate of Arthur Seat is a well known and excellent example. In some cases the stones are remarkably angular, giving the rock the character of a *breccia*, though this variety is much less frequent than the preceding. The fragmental detritus in the vents is often a dull, dirty-green gravel, partially cemented in an incoherent paste of the same composition. The small stones of the gravel consist chiefly of varieties of dolerite or basalt, usually much decayed. Larger blocks of the same rocks, as well as of sandstones, limestones, shales, &c., are scattered abundantly through the mass. This is the general character of the tuff filling up the vents in Fife. In districts where the lavas erupted have been porphyrites, the volcanic agglomerates and tuffs consist of the debris of these rocks. Fragments of older tuff may constantly be detected among the materials in the vents. The probable meaning of this fact has been already stated (*ante*, p. 461).

(*b*) In Interstratified Sheets.—The showers of dust, sand, and lapilli ejected from volcanic vents falling upon lakes, rivers, or the sea, sink to the bottom of the water, where they accumulate in layers, more or less mixed with the ordinary sand, mud, or other deposit. In proportion, therefore, to the vigour and length of the eruption and to the proximity of the vent will be the thickness of the layer of tuff and its freedom from extraneous materials. But as we recede from the centre of disturbance we find the volcanic debris to be more and more commingled with ordinary sediment until at last it comes to be no longer traceable in the usual sand or silt of the district. Hence, in dealing with the bedded tuffs of the Carboniferous system in the region of the Forth we are constantly presented with varying mixtures of fine volcanic debris and ordinary mechanical sediment. The reality and nature of this commingling can best be seen when the non-volcanic material is limestone, as may be instructively observed among the Kirkton Quarries to the east of Bathgate, and on the Fife coast between Pettycur and Kirkcaldy. (See *ante*, p. 482.)

The bedded tuffs vary according to the nature of the lavas with which they are associated. In the porphyrite districts they are dull red or greenish rocks, made up of fine porphyrite debris, mixed with ordinary sand and clay. In the doleritic and basaltic region they are almost invariably of a characteristic blackish-green to sage-green tint, rarely dull yellow or red; and are well stratified, the layers being marked off by lines of lapilli, consisting of greenish decayed varieties of basalt rocks. Their layers vary from mere laminæ, scarcely thicker than writing-paper, up to thick beds piled over each other to a depth of several hundred feet. Organic remains are frequently to be met with in these tuffs. Thus at the east quarry, Kirkton, we may observe well-preserved fronds of *Sphenopteris* and *Pecopteris*, with stems of *Lepidodendron* and *Calamites*; at the west quarry, *Productus longispinus*, crinoid stems, and other marine organisms; at St Anthony's Chapel, Arthur Seat, scales of *Rhizodus*, and other fish remains.

2. *Microscopic Characters.*—The fragmental rocks do not yield such satisfactory results as the crystalline masses to investigation with the microscope. In thin slices, with a low magnifying power, they are seen to present the same twofold composition as on the large scale to the naked eye, viz., enclosing paste and enclosed fragments.

a. The Paste.—I have never yet succeeded in obtaining any definite structure in the matrix of the tuffs. It is a dull, finely granular amorphous substance, which under a high power is resolvable into shapeless grains and shreds, often greenish, sometimes colourless, and sometimes black and opaque. There can be no doubt that these particles are merely the more thoroughly comminuted debris of the same materials as constitute the distinct lapilli. In no case have I found any microlites such as are met with in some modern volcanic tuffs and ashes. If any such ever existed, they have disappeared in the general oxidation and alteration of the matrix of the rock. The tuffs, being commonly porous incoherent masses, have suffered more from the influence of percolating water than the solid basalts. Probably we never see any of them now in their original condition; so that the diffused red, brown, and green matter of their base may represent microlites and crystals of some of the constituent minerals of the lavas.

Where the tuffs occur as beds or laminæ, interstratified with sedimentary rocks, the paste necessarily becomes mixed with the sand, mud, or limestone which may have been gathering in the floor over which the volcanic eruptions took place. Many good specimens showing this intermixture under the microscope may be gathered from the Bathgate and Pettycur localities already referred to.

b. The Lapilli.—These consist chiefly of rounded or subangular fragments of the lavas of the district in which the tuff lies. In Fife and the Lothians among the districts of basalt and dolerite, fragments of these rocks may be detected abundantly in the tuffs. Many of them do not differ in any respect from the substance of the solid rock as we see it now in sheets or in dykes at the surface. They seem to have been derived from the breaking up of already consolidated lava. This, so far as I have been able to observe, appears to be true also of the whole of the lapilli generally. It is rare to meet with one which has its cells drawn out round its circumference in such a manner as to point to its having been ejected from a molten mass and having acquired its globular form from rapid gyration in the air during its ascent. On the other hand, every section of tuff will furnish examples of cellular lapilli, in which the cells have been cut across by the external surfaces of the fragments. These lapilli are merely portions of vesicular or pumiceous lava, and may have been ejected by explosions that disrupted the hardened frothy crust of a rock, the lower portions of which were still molten and in ebullition underneath. So extremely cellular are many of the lapilli, that where they fell into water they must have floated for some time before becoming water-logged. The vesicles are filled with calcite, delessite, or some other product of decomposition.

One of the most generally diffused constituents of the tuff seems to be peculiar to them. In its present condition it is a serpentine or serpentinous substance, varying in colour from a bright grass-green or celadon-green to pale or honey-yellow, transparent and structureless in thin slices, looking at first like a green glass (see Plate XII. fig. 10). It is almost invariably cellular, sometimes so extremely so that the vesicles form three-fourths of the mass. The cavities are sometimes perfectly circular, and vary from less than $\frac{1}{1000}$ to more than $\frac{1}{100}$ of an inch in diameter. More usually they are elongated, and occasionally have been drawn out to such an extent that they appear as exceedingly thin parallel lines, giving the substance a laminated aspect. In some rare instances the elongation has taken place round the external parts of the lapilli, the inner cells remaining circular. But in almost all cases the vesicles have been broken across by the external surfaces of the lapilli. They appear usually empty in the preparations; but calcite occasionally remains in them

Besides the abundant cells, this substance frequently contains prisms of a triclinic felspar, and sometimes slender needles, which may be apatite. I have also observed round and subangular granules of quartz, containing abundant liquid cavities. This quartz is probably an accidental constituent caught up in the original melted rock, and not properly belonging to its composition. Scattered rod-like and granular black opaque microlites are sometimes observable. Very minute black grains may likewise be noticed, more particularly round the circumference of the cells.*

Viewed with ordinary light this green or yellowish transparent glass-like base of the lapilli at once suggests Palagonite. Between crossed Nicol prisms it is resolved into the pale bluish grey or neutral-tinted finely fibrous appearance, with occasional bright chromatic polarisation so characteristic of serpentine.

There can be no doubt that this serpentine or serpentinous substance must have been originally a glass, in the most thoroughly melted condition, and that it was kept in brisk ebullition by the passage of vapour through it. It has no counterpart among the lavas erupted at the surface. The nearest analogy is to be found in the Blackburn "pikrite" already described; but there is nothing in that rock like the minutely and abundantly cellular structure of the lapilli in the tuffs. These fragments occur chiefly in the tuff of vents; they abound in the necks of the Fife coast, sometimes to such an extent as nearly to constitute the entire mass of the tuff, as at Kilmundy Hill, near Burntisland. They may be observed in the later agglomerates of Arthur Seat, at St Magdalene's, Linlithgow, &c. They occur less frequently in the interstratified sheets of tuff, as among some of the beds at Pettycur and Kinghorn. I regard them as having been derived from the explosion of a rock which contained little felspar, but probably consisted mainly of olivine and augite, and which remained for a long while simmering, as it were, at the bottom of some of the volcanic vents. I have pointed out, in the case of the remarkable Blackburn rock, that a segregation of its materials had taken place, the heavy olivine remaining chiefly below. Something of the same kind may be supposed to have occurred in the volcanic funnels. After long fusion the lighter minerals, notably the felspar, may have come chiefly to the top, whence they might be discharged at successive volcanic eructations. Eventually the lower and

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* Since the above description was written, I have had an opportunity of examining the artificially fused products of some of the basalts and dolerites from the neighbourhood of Edinburgh (*ante*, p. 498, note). The resemblance of this altered serpentinous cellular substance, so abundant in some of the volcanic vents, to the glass obtained by fusing such a basalt as that of the Lion's Haunch, is so remarkable as at once to suggest an original similarity of condition. This glass, artificially obtained from some rocks like that of the Lion's Haunch, where the felspar resists fusion, must consist mainly of olivine and augite with diffused magnetic iron, and, as I have already said, it contains tufted microlites not unlike those of the tuff-lapilli.

heaver portions would be similarly ejected before the next great explosion, bringing up fresh streams of lava from below.

One of the most common constituents of the tuffs is quartz, in the form of rounded and subangular grains. When I first observed these enclosures I naturally supposed them to be merely the grains of sand that might have been in suspension in the water or moving along the floor over which the volcanic detritus settled. This may be partly their origin. But I am now convinced that they were directly ejected from the volcanic orifices in great quantity, for I find them in greater or less abundance in the tuff of all the vents. They are singularly uniform in character, consisting of water-clear quartz, free of enclosures, except abundant liquid-cavities, which may often be observed in lines across the diameter of the quartz-grain. These particles of quartz are manifestly derived from the destruction of some highly silicated rock. I have tried to account for their presence, on the supposition that they are due to the thorough trituration of quartzose sandstone. But this hardly accounts for their complete isolation from each other, for the want of any crust such as so frequently surrounds the quartz-grains of sandstones, and for the absence of fragments of sandstones which had escaped disintegration, and of pieces of shale and such other stratified rocks as could hardly fail to be present. As I have just mentioned, these separate quartz-grains are sometimes found within the solid substance of the serpentine lapilli. They must have been enclosed in the original olivine-rock while it was still molten.

Among the tuffs must be included some rocks, to which the name of volcanic mudstone may be applied. They are dull, dirty-green rocks, with a matrix varying from a fine impalpable hardened mud to a finely granular tuff, and containing lapilli and frequently fragments of shale, sandstone, limestone, &c. They occur at the margin of vents, wrapping round the projecting portions of the walls, and showing by wavy lines of flow distinct traces of having been in a pasty condition. To the east of Elie they rise through the tuff of the vents as dykes, which from their hardness rival basalt in their prominence above the surrounding softer tuff. One of these rocks is of an exceedingly close-grained texture, scarcely at first to be distinguished from a dull basalt, for which it has been mistaken. It has been already referred to as containing abundant pieces of a black cleavable hornblende and worn twin crystals of orthoclase. When the included fragments are carefully removed, their smooth surfaces leave a clean, sharp cast on the fine-grained mudstone. Examined with the microscope, the rock is found to consist of a dark-brown or greenish amorphous granular matrix crowded with small granules of quartz, with numerous minute lapilli of basalt rocks. It contains also occasional fragments of hornblende and plates of biotite.

EXPLANATION OF PLATES.

PLATE IX. Map of the Volcanic Districts in the Basin of the Firth of Forth.

PLATE X. Vertical Section of the Lower Part of the Carboniferous System in the Basin of the Firth of Forth, showing the succession of Volcanic Eruptions.

PLATE XI. Microscopic Structure of the Volcanic Rocks of the Basin of the Firth of Forth.

Fig. 1. Diabase, Crossall Hill, Linlithgowshire.—The felspar is chiefly orthoclase in Carlsbad twins, with the "herring-bone structure" described on p. 488. The augite occurs in large crystals and aggregations of crystals of a delicate claret colour. Some large crystals and a portion of a remarkable compound crystal of titaniferous iron are shown. The long white rod and the numerous colourless hexagonal sections are apatite. A few brown fibrous plates of biotite appear. (20 diameters.) See p. 487 *et seq.*

Fig. 2. Diabase, Corstorphine Hill, Edinburgh.—The augite is conspicuous in the centre of the field, surrounded by a turbid milky felspar. The opaque titaniferous iron appears to shade off into a whitish dull translucent substance (leucoxene). Patches of bright green decomposition products, sometimes with tufted fibrous structure, fill up some of the interstices. (20 diameters.) See p. 487 *et seq.*

Fig. 3. Dolerite, Dalmahoy Hill, Edinburgh.—An intrusive rock, showing abundant large clear prisms of a triclinic felspar, numerous large but rather ill-defined crystals of pale brownish pink augite, which has sometimes enclosed the felspar prisms. The titaniferous iron occurs in smaller forms than in the coarser diabases. Between the various minerals a considerable proportion of a ground-mass is interposed, which is in large measure devitrified by the appearance of microlites, and which now encloses a good deal of green decomposition-products in tufts, threads, and streaks. It is likewise traversed by clear needles of apatite, and marked by brown spots of limonitic discoloration. (20 diameters.) See p. 493.

Fig. 4. Anamesite, Craiglockhart Hill, Edinburgh.—This section is placed beside fig. 3 to show the distinction between intrusive and bedded rocks of the dolerite type. It shows a crystalline admixture of clear labradorite prisms, with abundant granular augite, through which are scattered a few large, well-formed crystals of the latter mineral, with crystals of olivine, usually serpentinised. One large well-defined olivine, with its green transverse decomposed portions and the central still comparatively fresh kernels, forms a prominent feature in the drawing. The iron is in very minute forms, and appears to be chiefly magnetite. (20 diameters.) See p. 501 *et seq.*

Fig. 5. Basalt, Kirkton East Quarry, Bathgate.—This section represents the structure of a typical interbedded basalt of the district. The rock evidently consists of an intimate mixture of minute prisms of labradorite and granular augite, between which clear interstices appear filled with a glassy ground-mass. A few well-defined usually compound crystals of augite are interspersed, but are not so abundant or conspicuous as the olivines, which are almost invariably converted into green serpentine. Octohedra of magnetite are tolerably uniformly dispersed through the rock. The minutely granular condition of the augite in this rock and in fig. 4 may be contrasted with that of the intrusive rocks Nos. 1, 2, and 3. (20 diameters.) See p. 501 *et seq.*

Fig. 6. Pikrite, Blackburn, Bathgate.—This rock consists mainly of serpentine of very varied texture and colour, containing numerous tolerably well-marked forms of the original olivine, and occasionally reticulated portions in which the distinct polarisation of the latter mineral may still be detected. The augite occurs in large admirably fresh well-defined crystals of a fine claret colour in thin slices. It often encloses crystals of olivine. A few fragments of magnetite or titaniferous iron are shown with here and there traces of their having been oxidised and hydrated into the brown hydrous peroxide of iron. (20 diameters.) See p. 504.

PLATE XII.

Fig. 7. Porphyrite, Pencraig Quarry, Garlton Hills.—A rock, consisting mainly of triclinic felspar, in small ill-defined prisms, with abundant grains, shreds, and crystals of magnetite and occasional augite. Traces of the oxidation and hydration of the iron are seen in the brown spots. (20 diameters.) See p. 508.

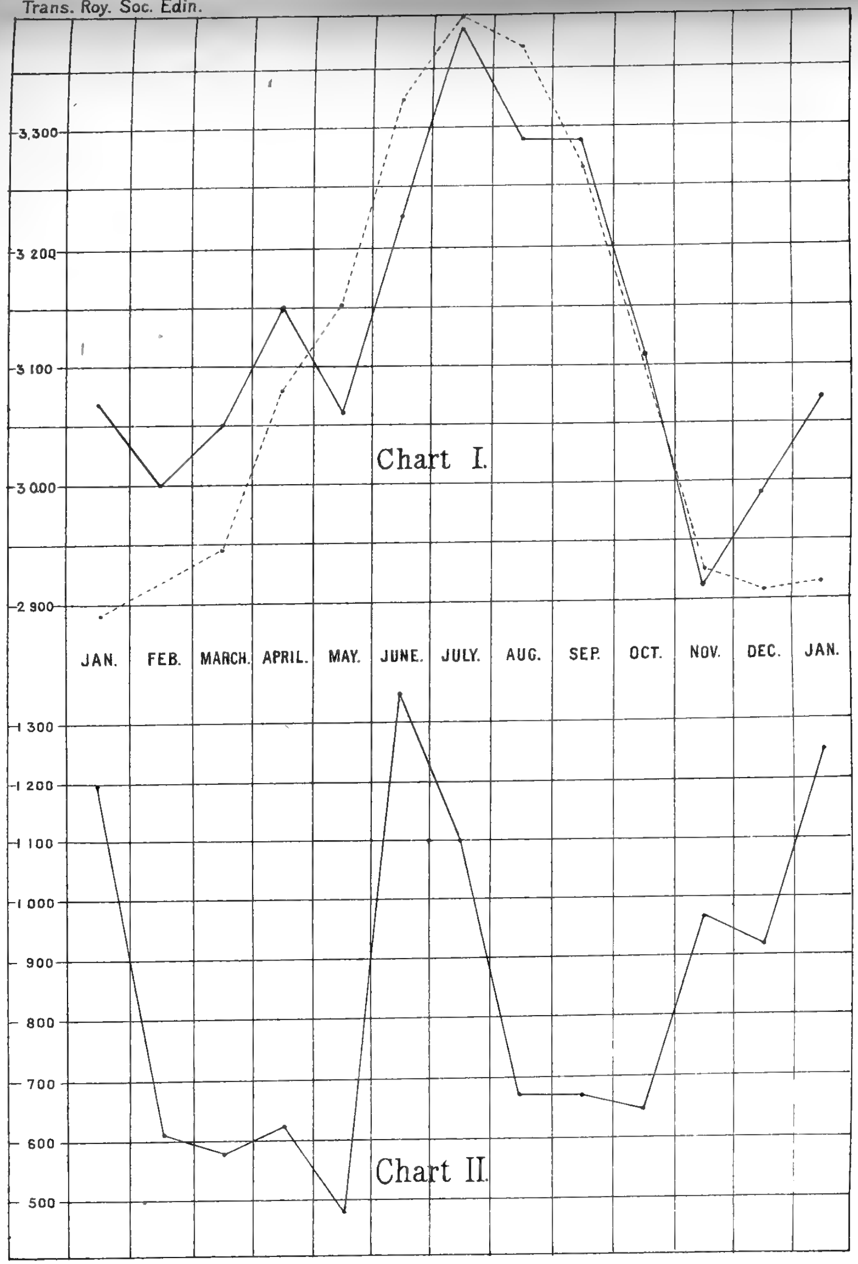
Fig. 8. Same as fig. 7, seen between crossed Nicol prisms. The ground-mass interposed between the felspar crystals now appears clouded, being partly quite dark and partly admitting a milky blue light. (20 diameters.)

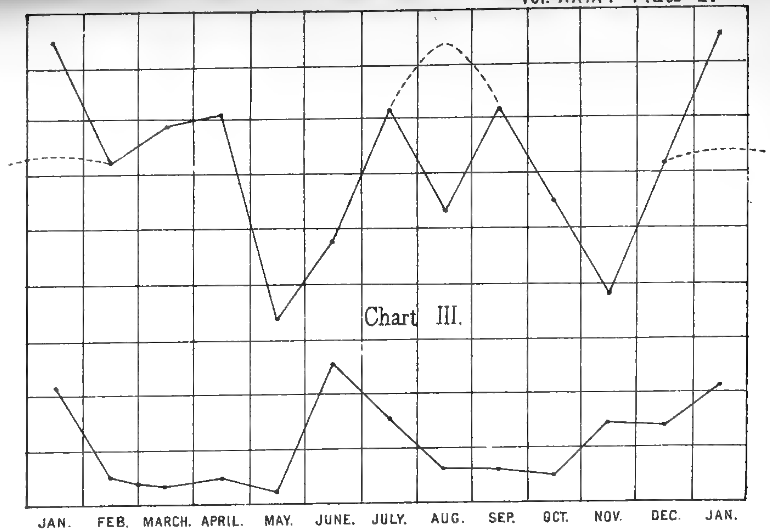
Fig. 9. Felsite, Volcanic Neck, Shore at Largo, Fife.—A finely granular felsitic ground-mass, with a kind of perlitic structure. In certain portions of the rock between the wavy lines of closer aggregation in the ground-mass, clear crystals of samidine and granules of quartz, with fluid cavities, are enclosed. (20 diameters.) See p. 510.

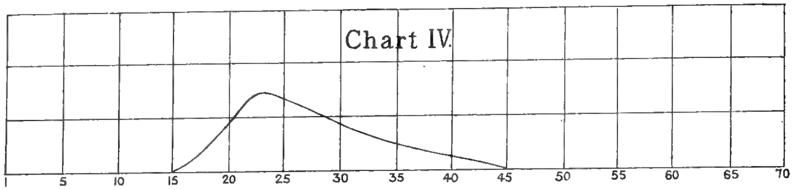
Fig. 10. Tuff, Kilmundy Hill, Burntisland.—An aggregate of irregular fragments of different lavas. The largest of these here shown consists of a bright green serpentinous substance, exceedingly cellular, and containing occasional plagioclase crystals and microlites (see p. 513). Between the lapilli much brown opaque decomposed matter is diffused.

Fig. 11. Veins of Dolerite traversing altered Shale, Salisbury Crags, Edinburgh.—The dolerite is exceedingly close-grained, becoming here and there, especially along the edges, quite black and opaque. At the lower portion of the field it is seen to be full of microlites of titaniferous iron or magnetite. It encloses numerous perfectly formed prisms of triclinic felspar. The shale consists of a porcellanised base, with clear round granules of quartz. See p. 497.

Fig. 12. Dolerite from edge of sheet near contact with sandstone, Gartness, Airdrie.—The large prisms of triclinic felspar and patches of titaniferous iron are the most conspicuous features. No augite appears, its place being probably taken by some of the abundantly diffused green decomposition products. The remarkable forms originally assumed by the iron, and preserved in those parts of rock which have been rapidly congealed, are shown in this drawing. See p. 496 *et seq.*







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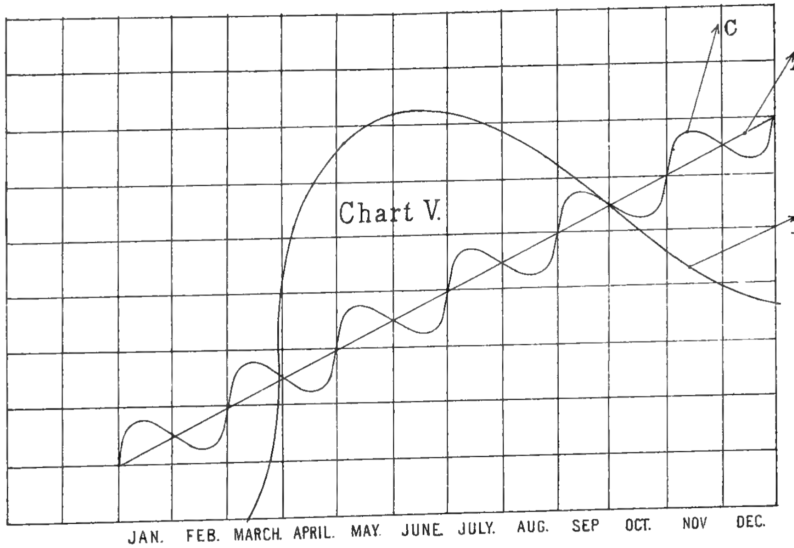

STEPS IN SPECTROSCOPY ACCORDING TO INCREASING TEMPERATURE,
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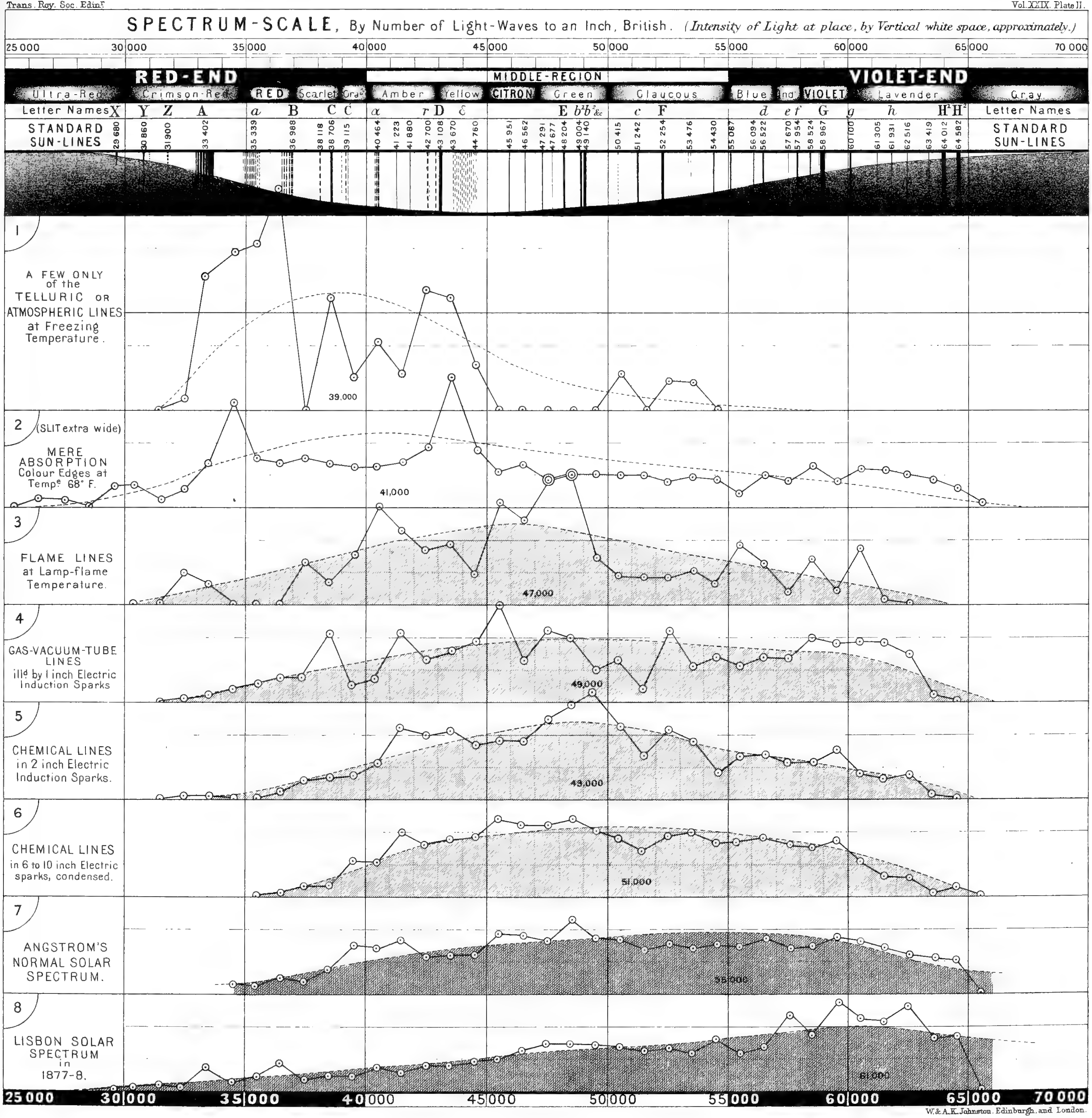

W. & A. K. Johnston. Edinburgh, and London.

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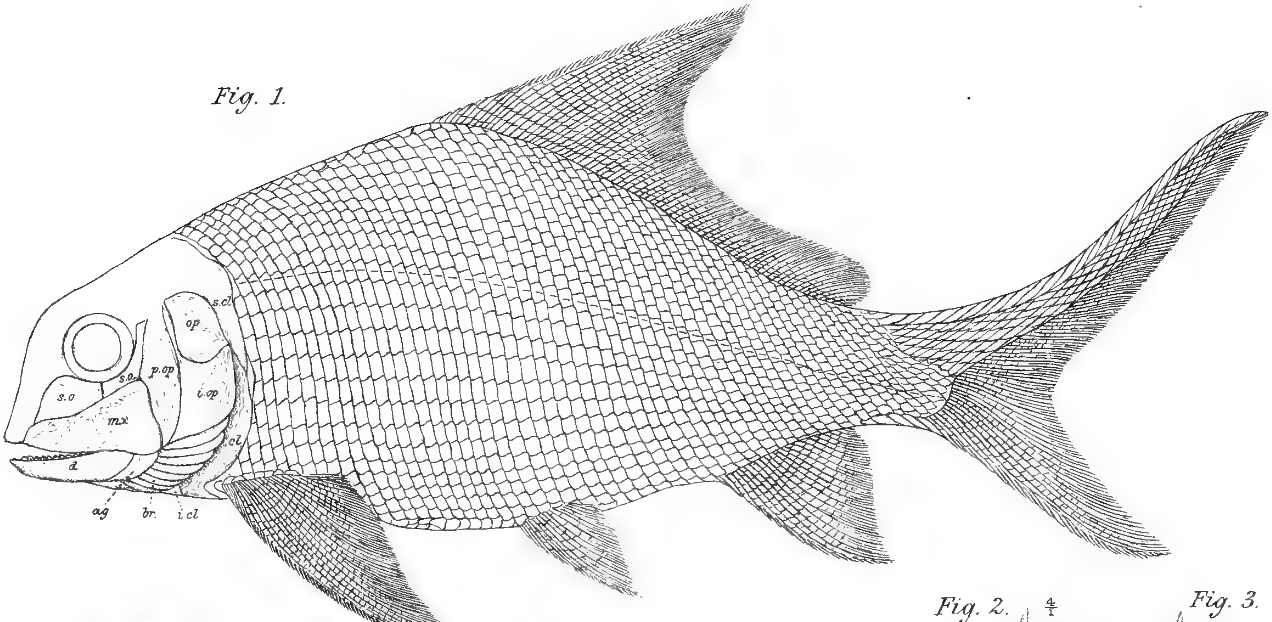

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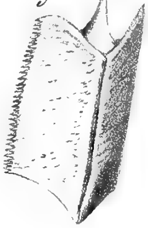

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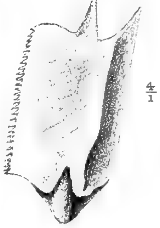

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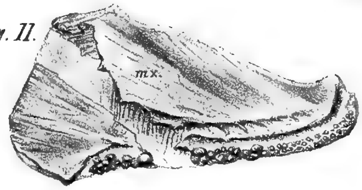

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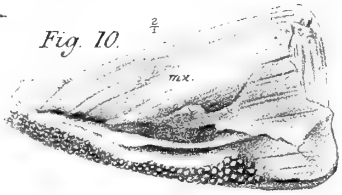

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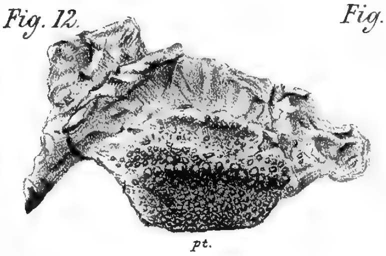

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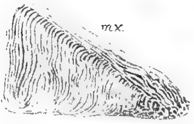

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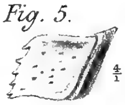

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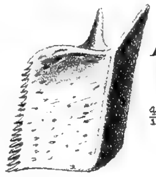

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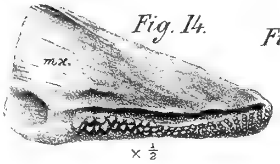

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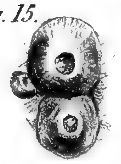

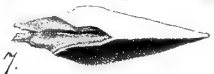

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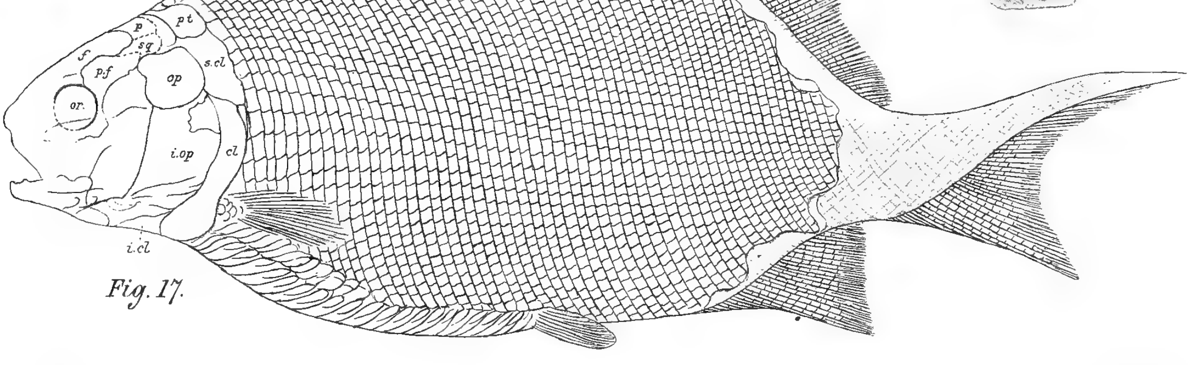

Fig. 17.

R.H. Traquair, M.D. delt

F. Huth, Lithr Edinr

Figs 1-16 EURYNOTUS, Fig. 17 BENEDENIUS.

Fig. 2.

Fig. 3.

Fig. 4.

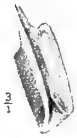

Fig. 5.

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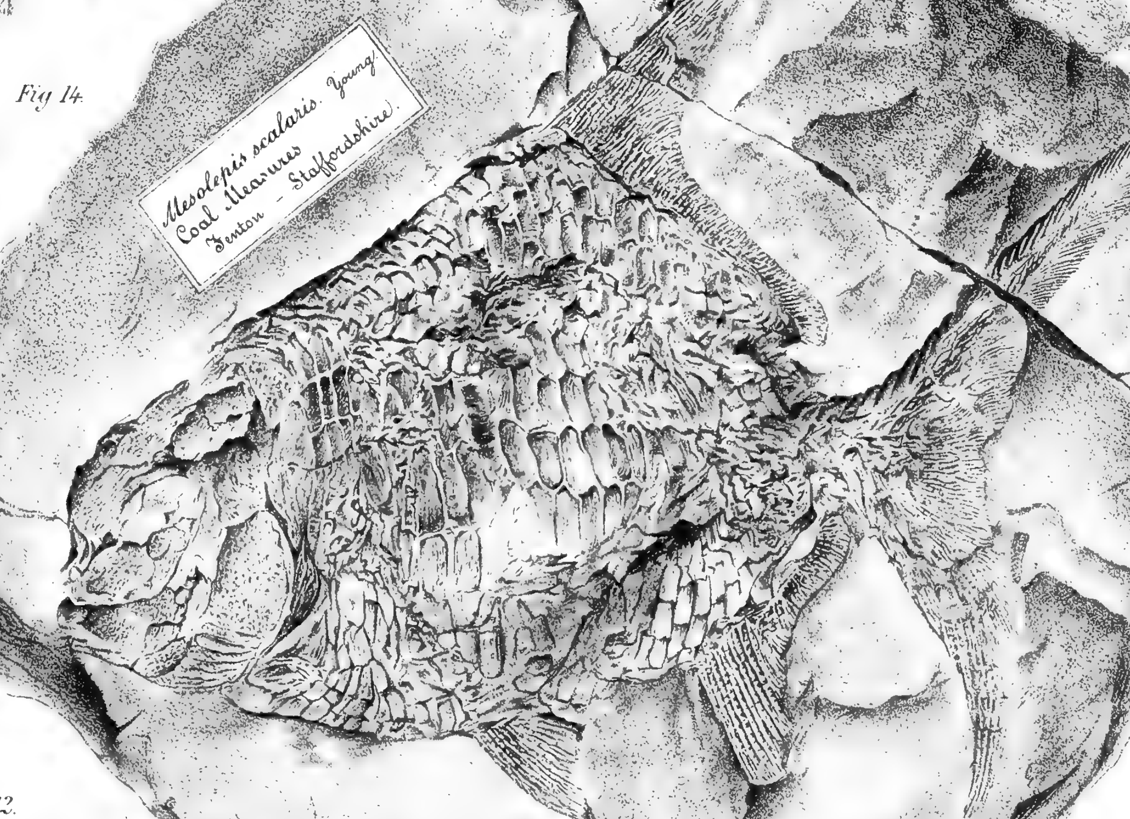

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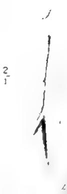

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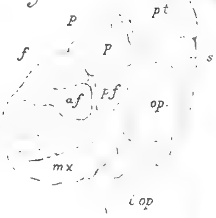

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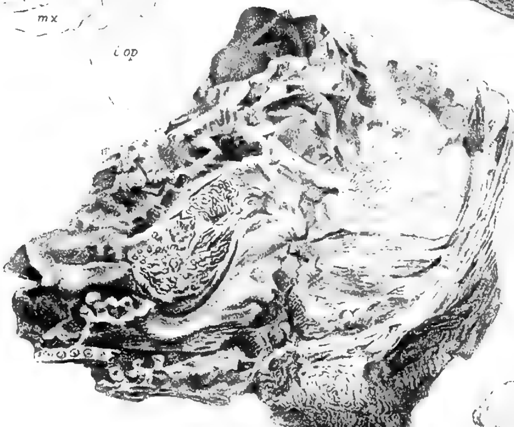

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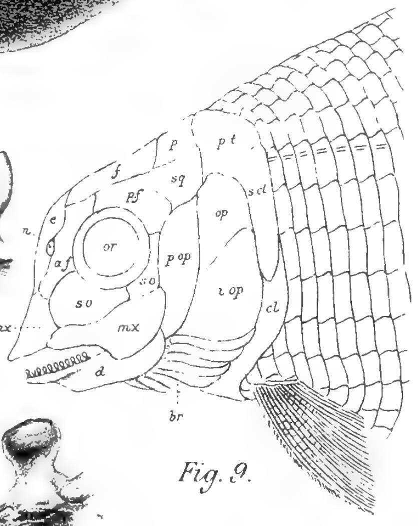

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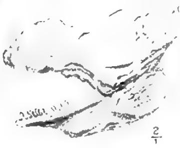

Fig. 6.

Fig. 11.

R.H. & P.A Traquair, del.

F Huth, Lith^{r} Edin^{r}

FIG^{s} 1-9, MESOLEPIS. 10-11, EURYSOMUS. 12-15, WARDICHTHYS.

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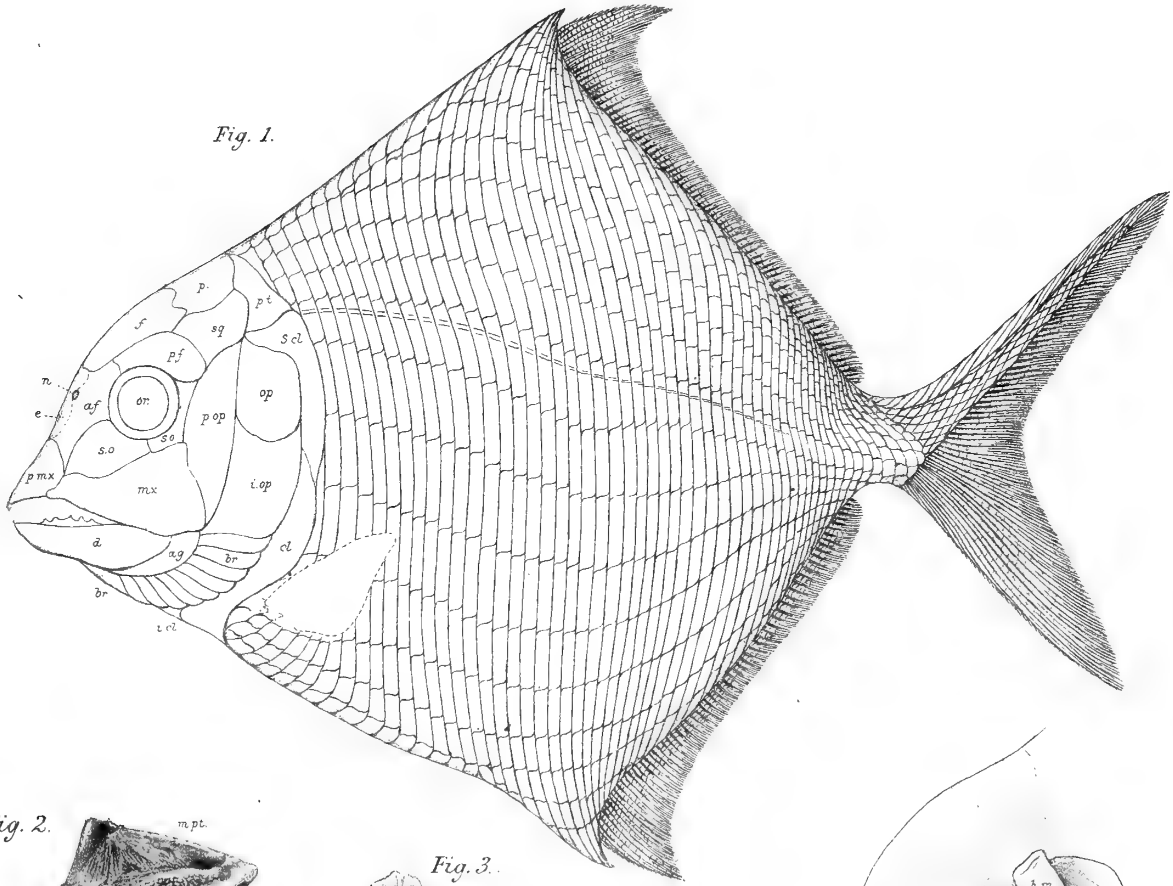

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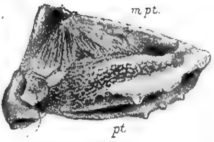

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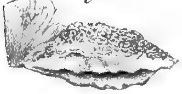

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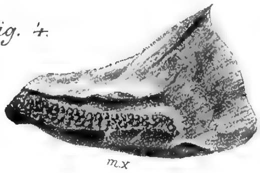

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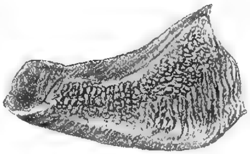

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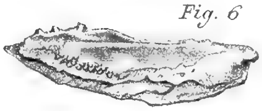

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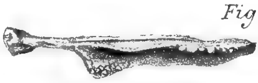

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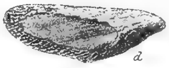

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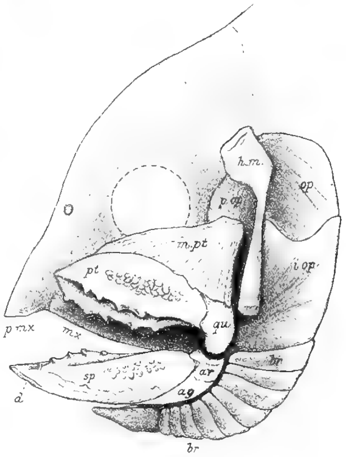

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

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F. Huth, Lithr Edinr

CHEIRODUS.

Fig. 2.

Fig. 3.

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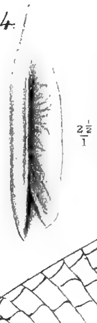

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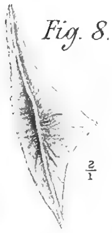

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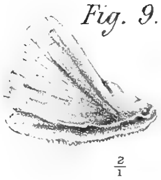

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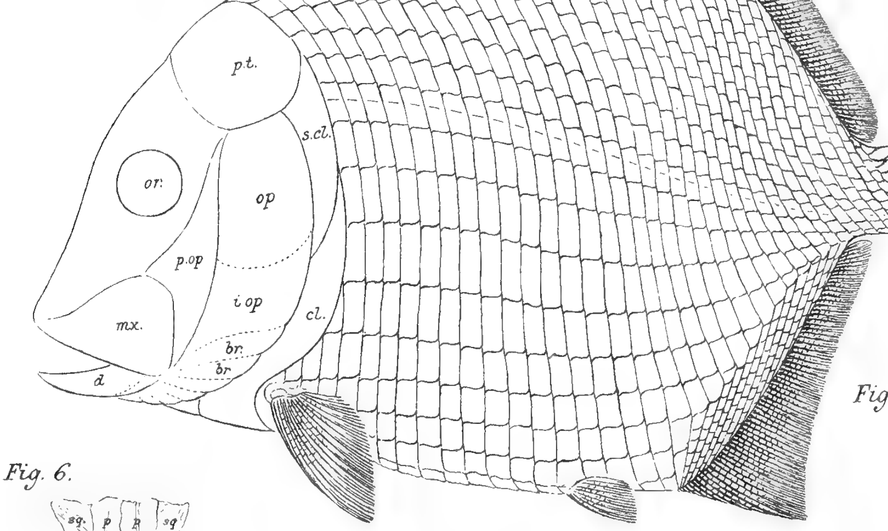

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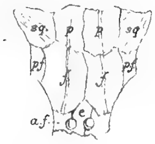

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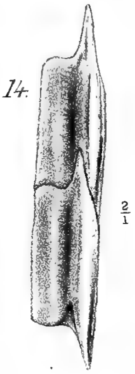

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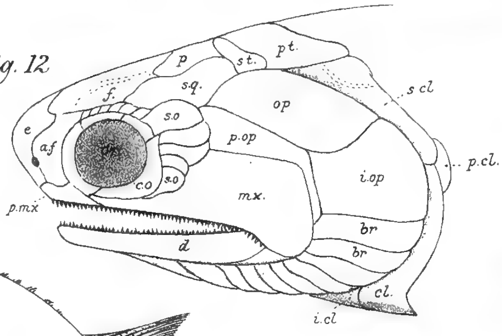

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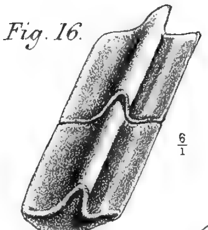

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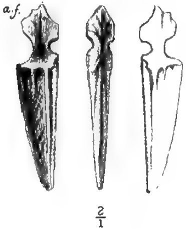

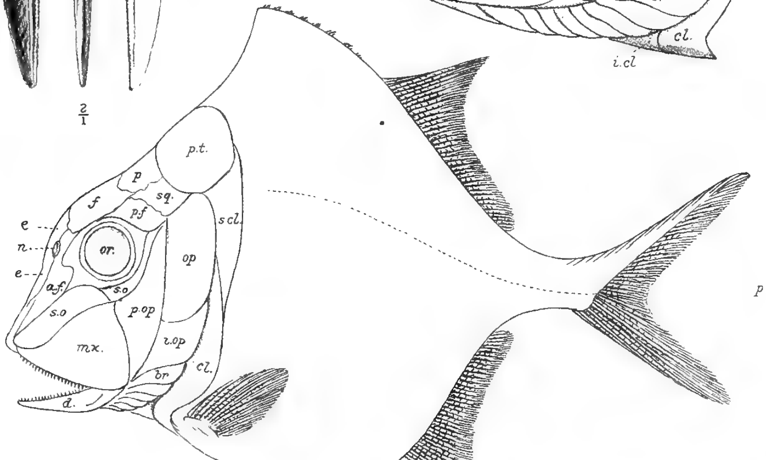

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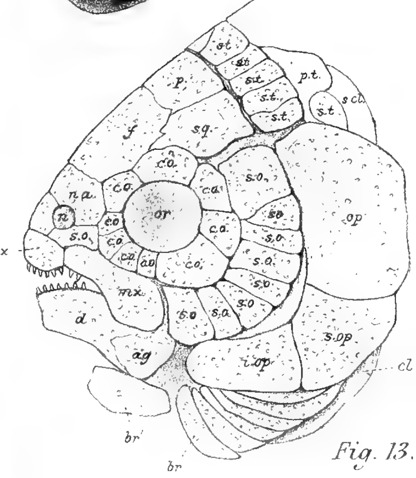

Fig. 13.

Fig. 11.

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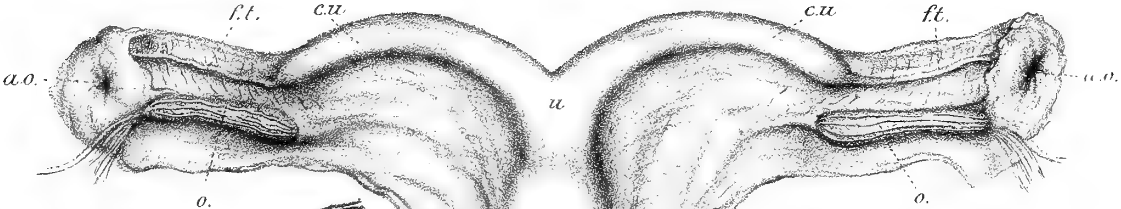
FIG^s. 1-11, PLATYSOMUS. 12 & 16, PALÆONISCUS. 13, DAPEDIUS. 14, 15, GYRODUS.



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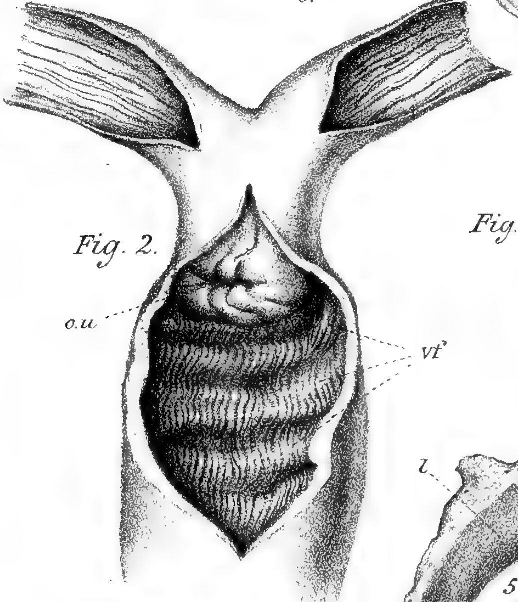

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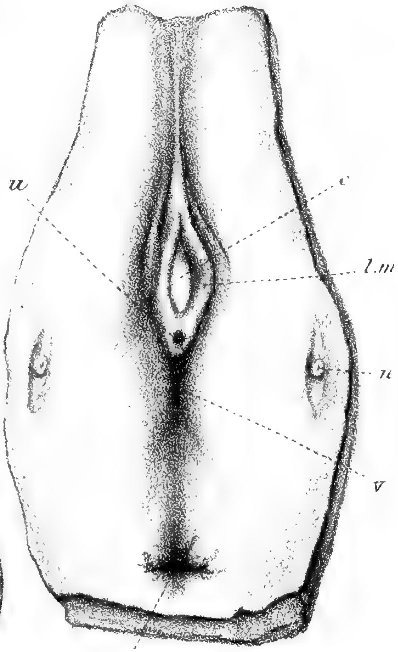

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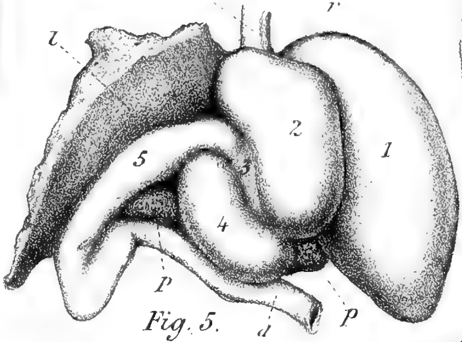

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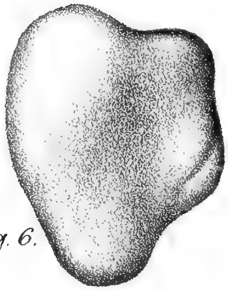

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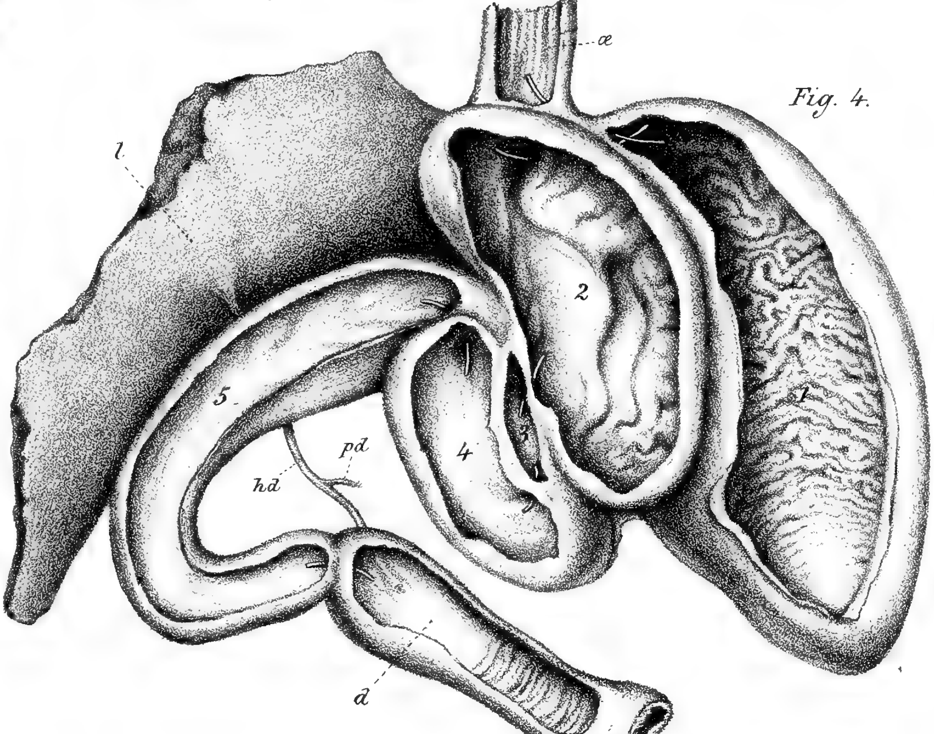

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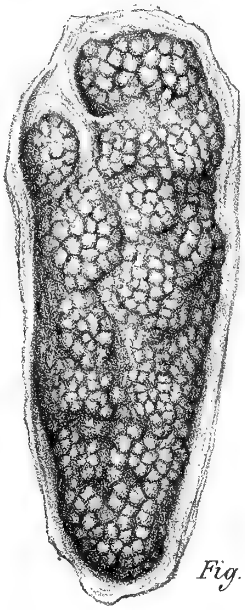

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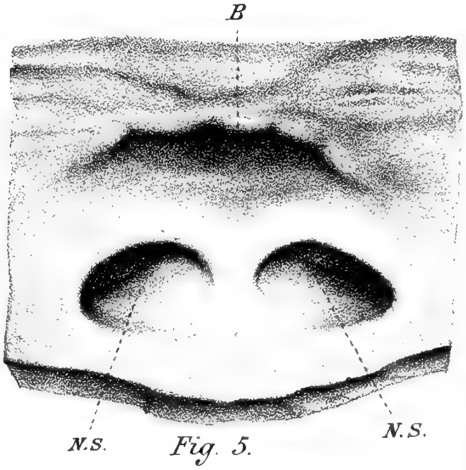
A.H.Young, M.B. del. C.Berjeau, F.L.S. lith. Waterston & Sons Lithrs. Edinr.



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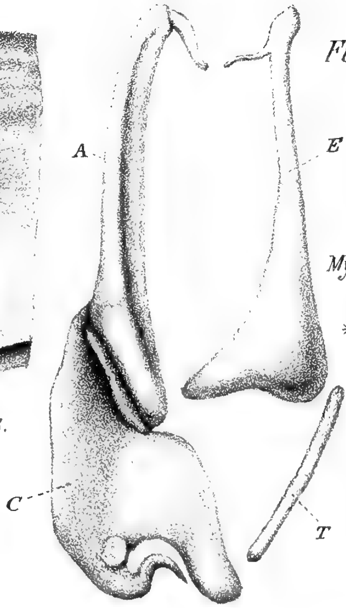

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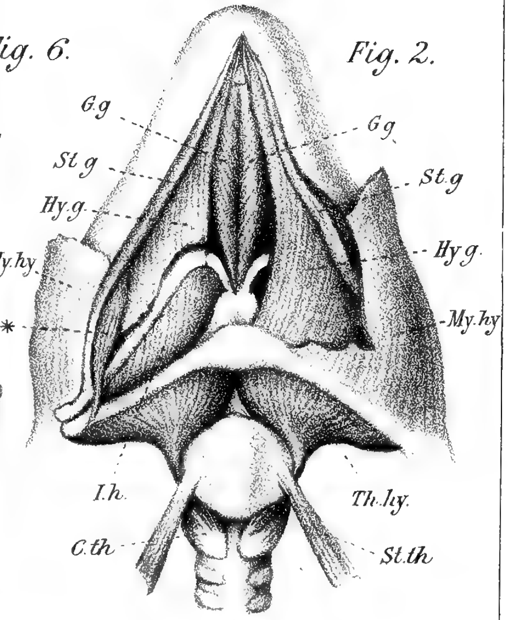

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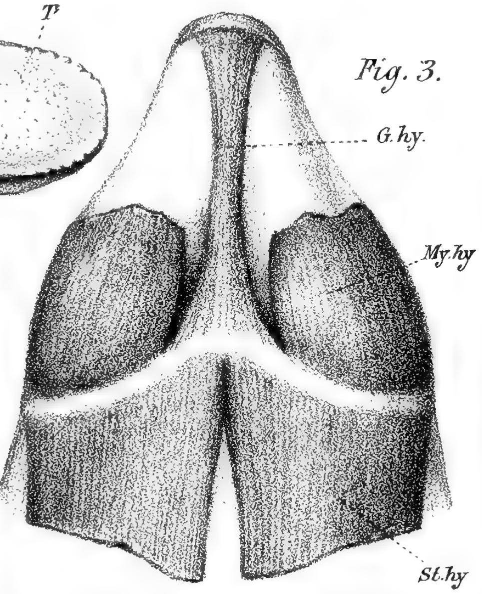

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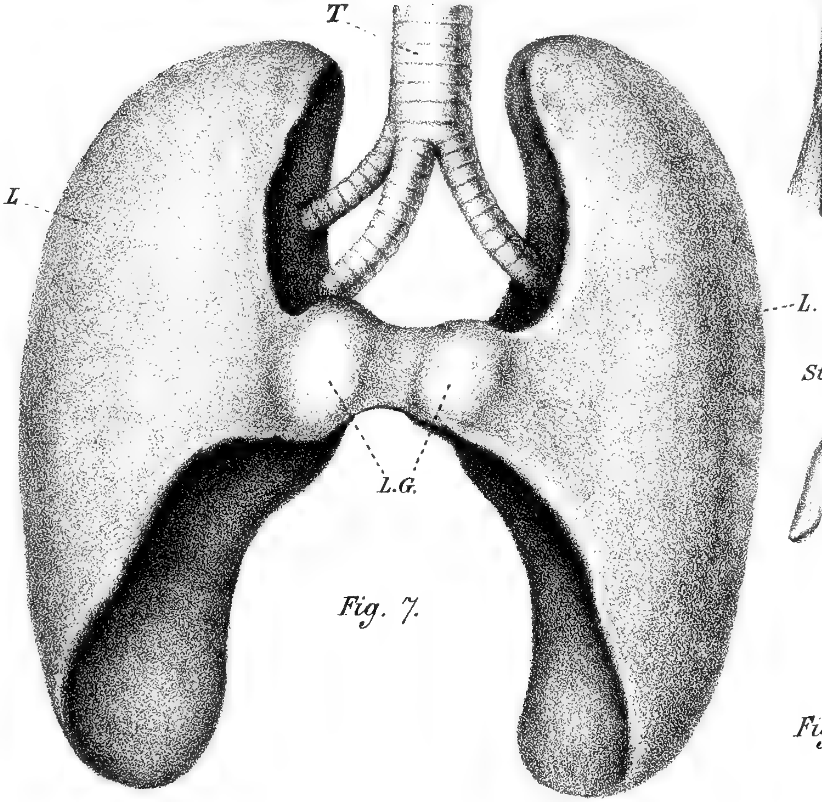

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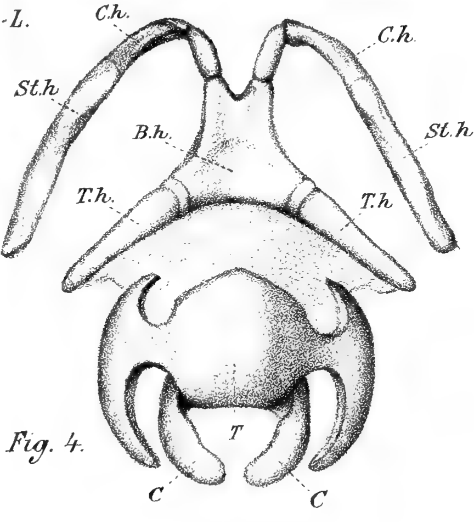

Fig. 4.

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C. Berjeau, F.L.S lith
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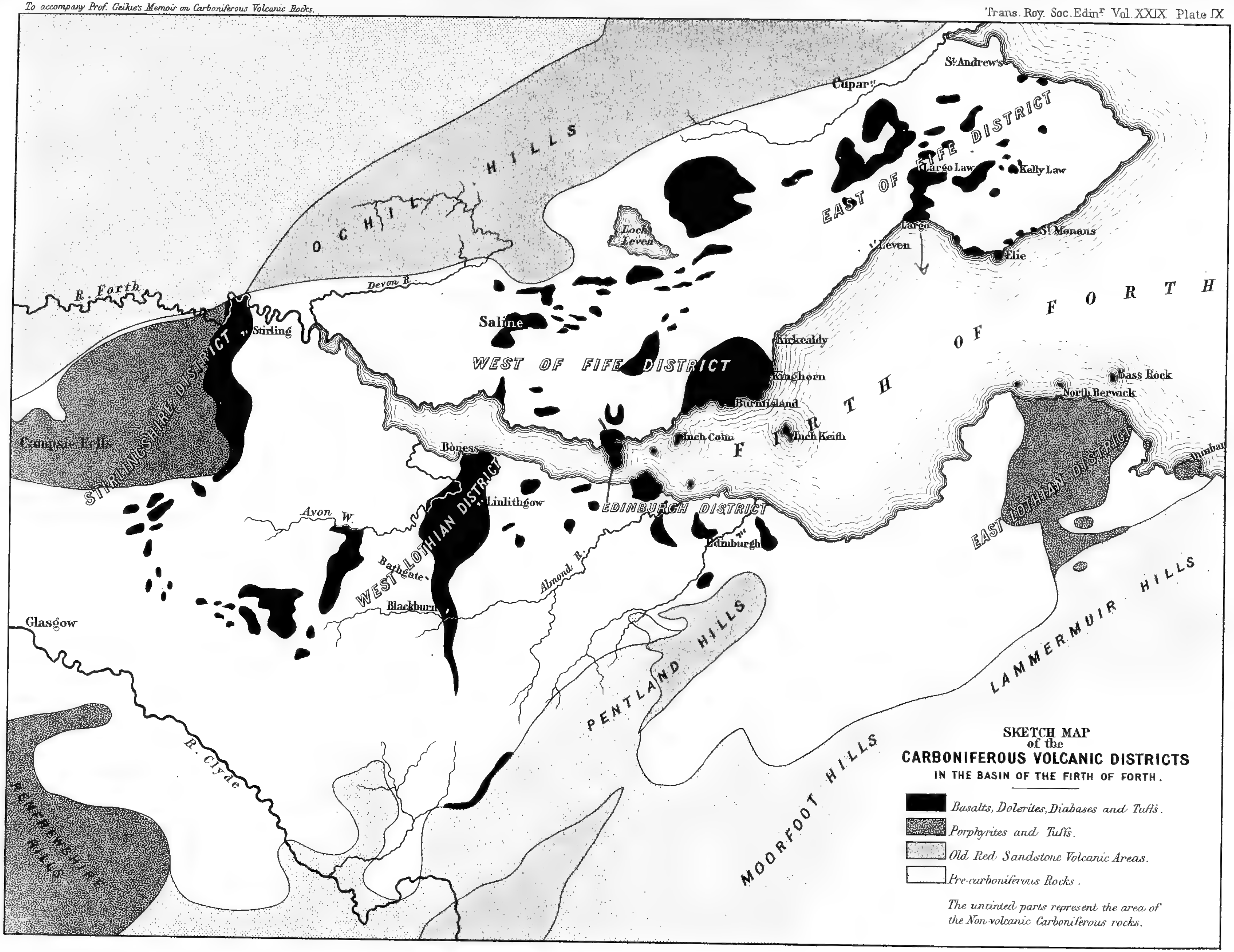


SKETCH MAP
of the
CARBONIFEROUS VOLCANIC DISTRICTS
IN THE BASIN OF THE FIRTH OF FORTH.

■	*Basalts, Dolerites, Diabases and Tuffs.*
▩	*Porphyrites and Tuffs.*
▨	*Old Red Sandstone Volcanic Areas.*
☐	*Pre-carboniferous Rocks.*

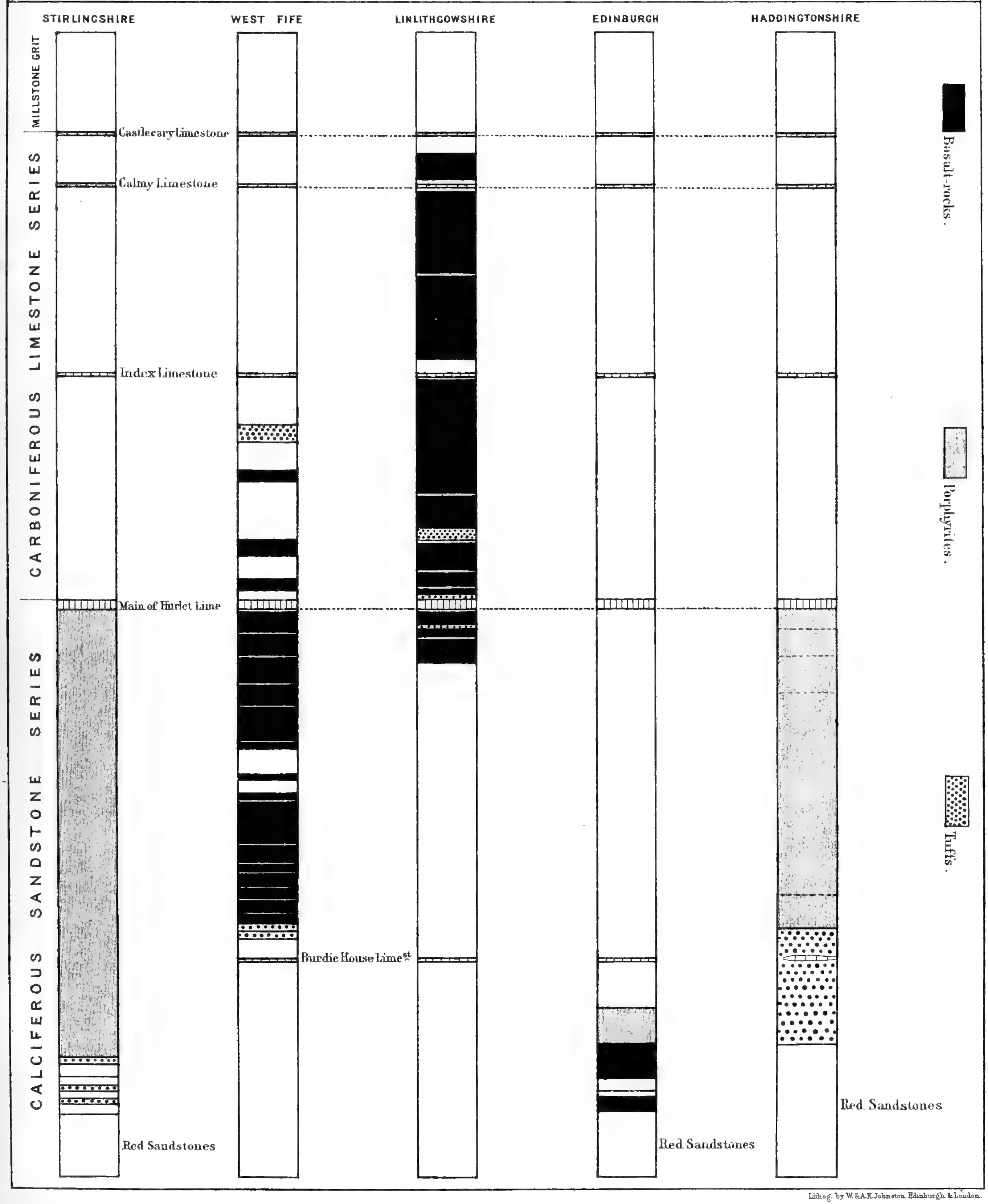
The untinted parts represent the area of the Non-volcanic Carboniferous rocks.

Lithᵍ by W. & A. K. Johnston, Edinburgh

To accompany Prof. Geikie's Memoir on Carboniferous Volcanic Rocks.

Trans. Roy. Soc. Edinr. Vol XXIX. Plate X.

SUCCESSION OF VOLCANIC ROCKS
IN THE CARBONIFEROUS SYSTEM OF THE BASIN OF THE FORTH.



Lithog. by W. & A.K. Johnston. Edinburgh & London.

To accompany Prof. Geikie's Memoir on Carboniferous Volcanic Rocks.

Trans Roy Soc Edin^r Vol XXIX Plate XI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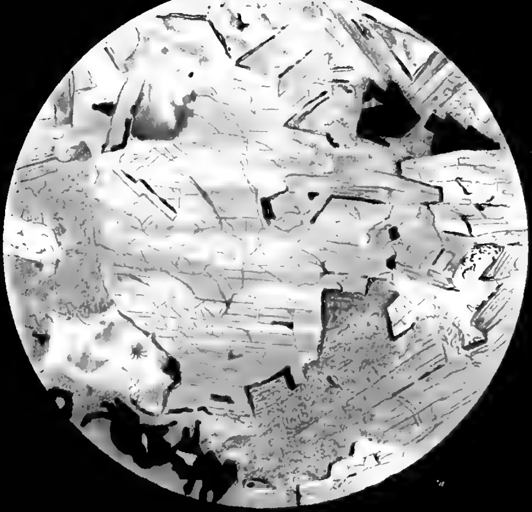
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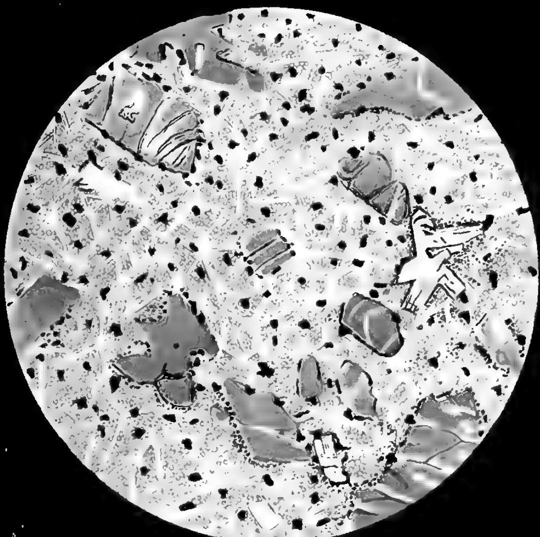
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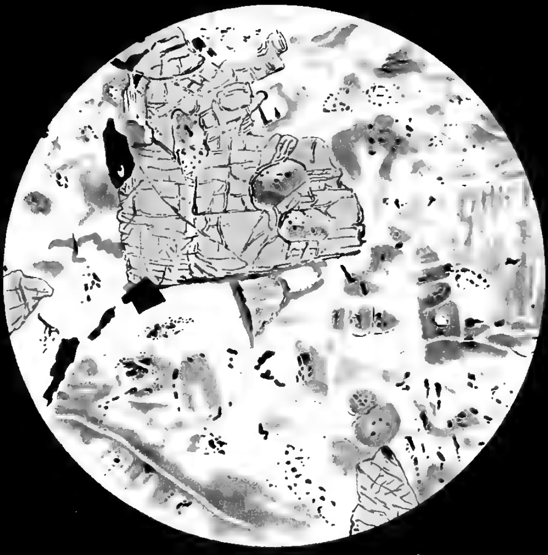
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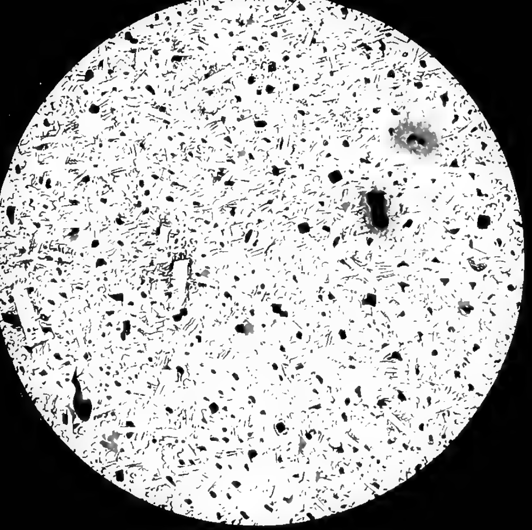
Drawn from Nature by A. Geikie

Chromo-Lithog by W & A K Johnston Edinburgh & London

To accompany Prof. Geikie's Memoir on Carboniferous Volcanic Rocks



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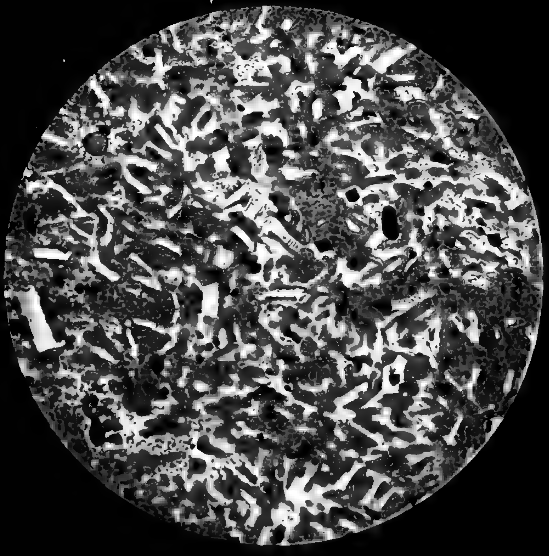

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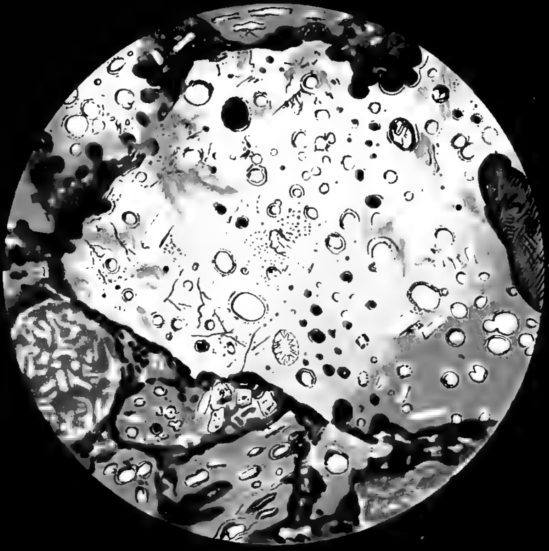

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XIII.—*On Minding's System of Forces.* By Professor CHRYSTAL.

(Received January 3, 1880. Read January 5, 1880.)

MINDING has proved a remarkable theorem concerning a variable system of forces defined as follows:—the points of application of the different forces and their magnitudes are given, while the directions are such that a pencil of rays through any given point parallel to them moves as a rigid body.

Besides MINDING'S original investigation, several others have been given since. The last of these, due to Professor TAIT, rests on purely quaternion methods, and is so elegant and concise that I was led to reinvestigate the whole subject by ordinary methods in the hope that the analysis might have some points of interest. Two methods of arriving at MINDING'S result are given, and a variety of other conclusions are arrived at by means of the second method, sufficient to indicate the course of a full investigation of the complex formed by the central axes, and of the congruency formed by the single resultants of MINDING'S system.

First Method.

The components of force and couple are found in terms of the RODRIGUES co-ordinates $\lambda\mu\nu$, which determines the position of the rigid pencil representing the direction of the forces. Let the rigid pencil be referred to moving rectangular axes $O\xi$, $O\eta$, $O\zeta$, fixed relatively to itself, which again are referred to the fixed axes Ox, Oy, Oz, by the system of direction cosines

$$\begin{array}{c|ccc} & x & y & z \\ \hline \xi & \lambda_1 & \mu_1 & \nu_1 \\ \eta & \lambda_2 & \mu_2 & \nu_2 \\ \zeta & \lambda_3 & \mu_3 & \nu_3 \end{array}$$

We shall have occasion to use the well-known relations between these direction cosines, and also their rational values in terms of RODRIGUES' co-ordinates. These last are (see SALMON, "Lessons on Higher Algebra," art. 44) as follows:—

$$\begin{array}{c|ccc} \hline & 1+\lambda^2-\mu^2-\nu^2, & 2(\lambda\mu+\nu), & 2(\lambda\nu-\mu) \\ & 2(\lambda\mu-\nu), & 1+\mu^2-\lambda^2-\nu^2, & 2(\mu\nu+\lambda) \\ & 2(\lambda\nu+\mu), & 2(\mu\nu-\lambda), & 1+\nu^2-\lambda^2-\mu^2 \end{array}$$

$$\div\ 1+\lambda^2+\mu^2+\nu^2$$

If X be the component of any force parallel to Ox, and $\xi\eta\zeta$ those parallel to Oξ Oη Oζ, we have

$$\mathrm{X}=\lambda_1\xi+\lambda_2\eta+\lambda_3\zeta, \text{ and so on.}$$

In choosing the two sets of axes we have nine constants at our disposal. Let them be so chosen that

$$\begin{array}{lll} \Sigma\xi=p & \Sigma\eta=0 & \Sigma\zeta=0 \\ \Sigma\xi x=0 & \Sigma\xi y=0 & \Sigma\xi z=0 \\ \Sigma\eta x=0 & \Sigma\eta y=pg & \Sigma\eta z=0 \\ \Sigma\zeta x=0 & \Sigma\zeta y=0 & \Sigma\zeta z=ph\,. \end{array}$$

With this understanding we get for the components of resultant force, and couple at O.

$$\left.\begin{array}{lll} \mathrm{P}=p\lambda_1\,, & \mathrm{Q}=p\mu_1\,, & \mathrm{R}=p\nu_1\,, \\ \mathrm{L}=pg\nu_2-ph\mu_3\,, & \mathrm{M}=ph\lambda_3\,, & \mathrm{N}=-pg\lambda_2\,; \end{array}\right\} \quad . \quad . \quad . \quad (1)$$

and for the equations to the single resultant when it exists,

$$\left.\begin{array}{ll} z\mu_1-y\nu_1+g\nu_2-h\mu_3=0 \\ x\nu_1-z\lambda_1 \qquad +h\lambda_3=0 \\ y\lambda_1-x\mu_1 \qquad -g\lambda_2=0\,. \end{array}\right\} \quad . \quad . \quad . \quad . \quad (2)$$

Multiplying by $\lambda_1\,\mu_1\,\nu_1$ and adding we get

$$(\lambda_1\nu_2-\lambda_2\nu_1)g+(\lambda_3\mu_1-\lambda_1\mu_3)h=0\,,$$

or

$$g\mu_3-h\nu_2=0\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In terms of $\lambda\mu\nu$ this becomes

$$(g+h)\lambda=(g-h)\mu\nu\,. \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Multiplying the equations in (2) by xyz and adding we get

$$(g\nu_2-h\mu_3)x+h\lambda_3y-g\lambda_2z=0\,,$$

which in terms of $\lambda\mu\nu$ becomes by the help of (4)

$$(hy-gz\lambda)\mu+(gz+hy\lambda)\nu+2(g+h)x\lambda=0\,. \quad . \quad . \quad (5)$$

Similarly from the first of (2) by the help of (4)

$$(y+z\lambda)\mu+(z-\lambda y)\nu+2(g+h)\lambda=0\,. \quad . \quad . \quad . \quad . \quad (6)$$

The equations (4) (5) (6) determine $\lambda\mu\nu$ when xyz are given.

Solving (5) and (6) for μ and ν, and then eliminating by means of (4), we get

$$\begin{gathered} \{(g-h)yz+2(hy^2+gz^2)\lambda-(g-h)yz\lambda^2\}^2 \\ +4(g^2-h^2)\lambda\{(x-g)z-(x+h)y\lambda\}\{(x-h)y+(x+g)z\lambda\}=0\,. \end{gathered}$$

This arranged according to powers of λ, gives

$$\begin{aligned}
&\lambda^4(g-h)^2y^2z^2 \\
&-\lambda^3 4(g-h)\{hy^2+gz^2+(g+h)(x+g)(x+h)\}yz \\
&+\lambda^2 2\{2(hy^2+gz^2)^2+2(g^2-h^2)(h^2y^2-g^2z^2)-(g-h)^2y^2z^2+2(g^2-h^2)x^2(z^2-y^2)\} \\
&+\lambda^1 4(g-h)\{hy^2+gz^2+(g+h)(x-g)(x-h)\}yz \\
&+\lambda^0(g-h)^2y^2z^2 \\
&\qquad\qquad = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)
\end{aligned}$$

Thus through a given point there pass in general four lines of the system. The lines of single resultant, therefore, form a congruency of the fourth order.

It will be seen, however, that

either $$z = 0 \text{ and } \frac{x^2}{h^2} - \frac{y^2}{g^2-h^2} = 1\,, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

or $$y = 0 \text{ and } \frac{x^2}{g^2} + \frac{z^2}{g^2-h^2} = 1\,, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (9)$$

makes the biquadratic (7) indeterminate inasmuch as either of these assumptions causes all the coefficients to vanish.

Hence we conclude that every line of the congruency intersects both these conics.

This may be farther verified by observing the values of $\lambda\mu\nu$ given by (5) and (6). When we put $z=0$ we get alternatively

$$\lambda = 0 \quad \mu = 0\,, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10)$$

or $$\left.\begin{aligned} \nu &= -\frac{(g+h)(x-h)}{hy} \\ \mu &= -\frac{(g+h)(x+h)\lambda}{hy}. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (11)$$

(11) in conjunction with (4) gives

$$\frac{x^2}{h^2} - \frac{y^2}{g^2-h^2} = 1\,,$$

that is so far as the second case is concerned all the rays that cut the plane of xy pass through the focal conic in that plane.

Next, if we put $y=0$ we get alternatively

$$\lambda = 0 \quad \nu = 0\,, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (12)$$

or $$\left.\begin{aligned} \nu &= -\frac{(g+h)(x'+g)}{gz'}\lambda \\ \mu &= +\frac{(g+h)(x'-g)}{gz'}. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

(13) along with (4) gives

$$\frac{x'^2}{g^2}+\frac{z'^2}{g^2-h^2}=1\,,$$

and we find as the condition that the $\lambda\mu\nu$ in (11) and (13) be the same

$$\frac{x^2-g^2}{g^2z^2}+\frac{x'^2-h^2}{h^2y'^2}=0$$

which is obviously satisfied by any pair of points on the two focal conics. The system of rays is, therefore, doubly infinite.

Returning to the alternatives in (10) and (12), we shall find them included in the general case.

Consider all the points in the plane of xy not lying on the conic (8) or the axis of x. For them $z=0$ and the biquadratic has two roots $=0$, and two $=\infty$.

The former case, using (5) and the last of (2), gives $\lambda=0\quad\mu=0$, whence $\nu_1=0\quad\lambda_2=-\mu_1$

and
$$\frac{\lambda_1}{\mu_1}=\frac{y}{x-g}\quad\text{. . . . .}\qquad(14)$$

The latter gives
$$\lambda=\infty\quad\mu=\infty\quad\frac{\lambda}{\mu}=\frac{g-h}{g+h}\nu\,,$$

whence
$$\nu_1=0\quad\lambda_2=\mu_1$$

$$\frac{\mu_1}{\lambda_1}=\frac{y}{x+g}\quad\text{. . . . .}\qquad(15)$$

In both these cases, therefore, we get rays lying in the plane xy and passing through points $x=\pm g$ on the axis of x, *i.e.*, passing through the vertices of the focal conic in the plane of xz.

Similarly, we may shew that all rays passing through points in the plane of xz not lying on the focal conic, lie wholly on that plane and pass through the vertices of the focal conic in the plane of xy.

We get, therefore, no addition to the rays intersecting the two conics.

An examination of the rays passing through points on the axis of x, for which $y=0$ and $z=0$, so that (7) is apparently indeterminate, leads also to nothing new, for we get the axis of x itself and rays in the planes of xy and xz passing through the points $x=\pm g=\pm h$.

Hence we are led to our original conclusion, that the single resultants in MINDING'S system consists solely of the congruency of lines intersecting the two focal conics (8) and (9).

Second Method.

Formulæ connecting the co-ordinates of the foot of the perpendicular on a central axis or single resultant.

If
$$\xi = \frac{\text{MR}-\text{NQ}}{p^2} = g\mu_1 . \lambda_2 + h\nu_1 . \lambda_3 \quad . \quad . \quad . \quad . \quad (1)$$
$$\eta = \quad \&\text{c.} \quad = g\mu_1 . \mu_2 + h\nu_1 . \mu_3 \quad . \quad . \quad . \quad (2)$$
$$\zeta = \quad \&\text{c.} \quad = g\mu_1 . \nu_2 + h\nu_1 . \nu_3 \quad . \quad . \quad . \quad (3)$$

in terms of former notation, the equation to the central axis is

$$\frac{x-\xi}{\lambda_1} = \frac{y-\eta}{\mu_1} = \frac{z-\zeta}{\nu_1};$$

and it is easy to see that $\xi\eta\zeta$ are the co-ordinates of the foot of the perpendicular from the origin upon it.

If ρ denotes the length of this perpendicular, we get by squaring (1) (2) (3) and adding,

$$\rho^2 = g^2\mu_1^{\ 2} + h^2\nu_1^{\ 2} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If the central axis be a line of action of a single resultant, we have as we saw before

$$g\mu_3 = h\nu_2 \, . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Using (6) we get at once from (5) (2) (3)

$$\rho^2 = g^2\mu_1 . \mu_1 + h^2\nu_1 . \nu_1$$
$$g\eta = g^2\mu_1 . \mu_2 + h^2\nu_1 . \nu_2$$
$$g\zeta = g^2\mu_1 . \mu_3 + h^2\nu_1 . \nu_3$$

whence

$$\rho^4 + g^2\eta^2 + h^2\xi^2 = g^4\mu_1^{\ 2} + h^4\nu_1^{\ 2} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The equations (5) and (7) form the basis of the following discussion; (5) holds for all central axes, and is the onefold relation that determines the complex which they form; (5) and (7) taken together give the twofold relation which determines the congruency of single resultants.

In what follows we shall replace the equations (5) and (7) by

$$\rho^2 = f^2\lambda_1^{\ 2} + g^2\mu_1^{\ 2} + h^2\nu_1^{\ 2} \quad . \quad . \quad . \quad . \quad . \quad (8)$$
$$\rho^4 + f^2\xi^2 + g^2\eta^2 + h^2\zeta^2 = f^4\lambda_1^{\ 2} + g^4\mu_1^{\ 2} + h^4\nu_1^{\ 2} \quad . \quad . \quad . \quad (9)$$

The formulæ thus found will be more symmetrical, and MINDING'S case is obtained by putting $f=0$.

On the Complex of Central Axes.

From the equation

$$\rho^2 = f^2\lambda_1{}^2 + g^2\mu_1{}^2 + h^1\nu_1{}^2$$

we get at once for the locus of all the rays passing through a given point *abc*

Complex-cone.

$$f^2(x-a)^2 + g^2(y-b)^2 + h^2(z-c)^2$$
$$= (bz-cy)^2 + (cx-az)^2 + (ay-bx)^2 , \quad . \quad . \quad (10)$$

a cone of the second degree. The complex is, therefore, of the second order.

Complex cylinder.

As a particular case of this we see that all the rays of the complex parallel to a given line (*lmn*) lie on the right circular cylinder where radius is

$$\sqrt{f^2l^2 + g^2m^2 + h^2n^2} \cdot$$

The locus of the feet of the perpendiculars on the generators of the complex-cone is the curve of the fourth degree, common to (10), and the sphere

$$r^2 = ax + by + cz . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

In the case of the complex cylinder this locus is, of course, a circle.

Complex conic.

Since any plane through the vertex of the complex-cone cuts it in two generators, we see that through every point of a given plane there pass two rays of the complex. Hence all the rays in a given plane envelop a conic.

If we consider all the conics in planes parallel to a given plane, the complex conics generate PLÜCKER's equatorial surface.

Equatorial surface.

Let the equation to one of the planes be

$$lx + my + nz = p \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Putting $\xi = x - a \quad \eta = y - b \quad \zeta = z - c ,$

we have from (10)

$$A\xi^2 + B\eta^2 + C\zeta^2 - 2D\eta\zeta - 2E\zeta\xi - 2F\xi\eta = 0 , \quad . \quad . \quad (13)$$

and $l\xi + m\eta + n\zeta = 0 , \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$

where $A = r^2 - x^2 - f^2$, &c. $D = yz$, &c.

The resulting envelope is given by the equation of the fourth degree

$$\begin{vmatrix} A & -F & -E & l \\ -F & B & -D & m \\ -E & -D & C & n \\ l & m & n & 0 \end{vmatrix} = 0 \quad . \quad . \quad . \quad . \quad . \quad (15)$$

or $$(D^2-BC)\,l^2+(E^2-CA)\,m^2+(F^2-AB)\,n^2$$
$$-2(AD+EF)\,mn-2(BE+FD)\,nl-2(CF+DE)\,lm=0$$

Meridian surface.

If we consider the conics corresponding to all the planes that pass through a given line, we get a surface which PLÜCKER calls the meridian surface of the conic.

It is obvious that this surface is the envelope of the complex-cones whose vertices lie on the given line.

Let the equations to the given line be

$$lx+my+nz+p=0$$
$$l'x+m'y+n'z+p'=0\,.$$

It is easily seen that the equation to the envelope will be (15), with $P'l-Pl'$, $P'm-Pm'$, $P'n-Pn'$ written in place of lmn,

where $$P=lx+my+nz-p$$
$$P'=l'x+m'y+n'z-p'\,.$$

So that, putting $\alpha=mn'-m'n$, $\varpi=p'l-pl'$, and so on;

$$U=\gamma y-\beta z \qquad V=\alpha z-\gamma x \qquad W=\beta x-\alpha y\,,$$

and noticing that

$$D^2-BC=r^2(g^2+h^2)-h^2y^2-g^2z^2-g^2h^2-r^2x^2=S-r^2x^2 \text{ say,}$$

and $$AD+EF=-(f^2-r^2)yz\,,$$

we get for the equation to the meridian surface

$$(S-x^2r^2)(\varpi+U)^2+\text{ \&c. }+2(f^2-r^2)yz(\rho+V)(\sigma+W)+\text{ \&c. }=0 \quad . \qquad (16)$$

this equation is *apparently* of the sixth degree; but the terms of the sixth degree are equal to

$$r^2(xU+yV+zW)^2\,,$$

and those of the fifth to

$$2r^2(\varpi x+\rho y+\sigma z)(xU+yV+zW)\,,$$

which vanish identically, so that the degree is really the fourth.

Exploration of the Complex by central radii.

On rays of the complex that intersect a given line.

From what we have already proved it follows that through any point of a given line there pass in general two rays parallel to a given plane.

This affords us convenient means for exploring the complex by drawing radii through the centre.

We shall in the first place investigate the rays passing through any radius and perpendicular to it.

If ρ be the distance of any point on the radius (lmn) from the centre, the direction cosines of the two rays are given by

$$(\rho^2-f^2)\lambda^2+(\rho^2-g^2)\mu^2+(\rho^2-h^2)\nu^2=0\,, \quad . \quad . \quad (17)$$

$$l\lambda+m\mu+n\nu \qquad =0\,. \quad . \quad . \quad (18)$$

The most important question is whether the pair of rays is real for all points of the radius. If f^2 g^2 h^2 be all positive and different from zero, it is clear that no ray can pass through the centre; and, if they are all finite, no ray can be at an infinite distance from the centre.

In other words, there must in general be maxima and minima values of ρ. The finding of such when the conditions are as in (17) and (18) leads, as is well known, to the following results—

$$\frac{l^2}{\rho^2-f^2}+\frac{m^2}{\rho^2-g^2}+\frac{n^2}{\rho^2-h^2}=0 \quad . \quad . \quad . \quad . \quad (19)$$

$$\lambda:\mu:\nu::\frac{l}{\rho^2-f^2}:\frac{m}{\rho^2-g^2}:\frac{n}{\rho^2-h^2} \quad . \quad . \quad . \quad . \quad (20)$$

(19) gives the maxima and minima values of ρ^2, and (20) gives the direction cosines of the corresponding rays, which, as may be easily verified, are at right angles to each other.

It is easy to see, moreover, that the roots of (19) are always real and positive, for if f^2 g^2 h^2 be in order of magnitude they clearly include the roots in their intervals.

Another method leads to interesting results.

If θ be the angle between the rays whose direction cosines are given by (17) and (18) when ρ is assigned, then we get very easily

$$\tan\theta=\frac{2\sqrt{-\{l^2(\rho^2-g^2)(\rho^2-h^2)+m^2(\rho^2-h^2)(\rho^2-f^2)+n^2(\rho^2-f^2)(\rho^2-g^2)\}}}{(m^2+n^2)f^2+(n^2+l^2)g^2+(l^2+m^2)h^2-2\rho^2} \quad . \quad (21)$$

Hence if $\rho_1{}^2$ and $\rho_2{}^2$ be the roots of the equation (19), in order that θ may be a real angle ρ^2 must be between $\rho_1{}^2$ and $\rho_2{}^2$. When $\rho^2=\rho_1{}^2$ or $=\rho_2{}^2$, $\theta=0$; and when $\rho^2=\frac{1}{2}(\rho_1{}^2+\rho_2{}^2)$, $\theta=\frac{\pi}{2}$. The last of these results is a particular case of the theorem, obviously true from (8), that, if $\rho_1\ \rho_2\ \rho_3$ be the perpendiculars from the centre on three rays whose directions are mutually at right angles, then

$$\rho_1{}^2+\rho_2{}^2+\rho_3{}^2=f^2+g^2+h^2=\text{const.} \quad . \quad . \quad . \qquad (22)$$

and if ρ_1 and ρ_2 be the perpendiculars on two rays perpendicular to each other, and to a fixed line, then

$$\rho_1{}^2+\rho_2{}^2=\text{const.}$$

(*Inserted May* 1, 1880.)

[The results of (19), (20), and (22) shew the close analogy of the properties of the complex with those of a quadric surface. Taking this point of view, and starting from (17) and (18), we are led to many interesting results, among which the following is noteworthy.

The perpendicular rays at any point of the radius $(l\,m\,n)$ make equal angles with the extreme double rays; and, if θ be the angle they make with the extreme ray whose distance from the origin is ρ_1, then

$$\rho^2=\rho_1{}^2\cos{}^2\theta+\rho_2{}^2\sin{}^2\theta, \quad . \quad . \quad . \qquad (23)$$

which of course contains, as particular cases, some of the results already obtained. This formula has an interesting resemblance to HAMILTON'S elegant relation, connecting the shortest distance from any ray of a congruency to any consecutive ray with the shortest distances corresponding to the virtual foci of that ray. See SALMON, "Geometry of Three Dimensions," 3d edition, p. 567.]

As the result of the above discussion we have the following.

The surface of the fourth degree

$$2r^4=(g^2+h^2)x^2+(h^2+f^2)y^2+(f^2+g^2)z^2 \quad . \quad . \qquad (23)$$

is the locus of points at which the two rays perpendicular to the central radius are perpendicular to each other.

The surface

$$\frac{x^2}{r^2-f^2}+\frac{y^2}{r^2-g^2}+\frac{z^2}{r^2-h^2}=0, \quad . \quad . \quad . \qquad (24)$$

which is the reciprocal of the wave surface, is the locus of points at which the two rays perpendicular to the central radius coincide, and the space between its two sheets is the solid locus of the feet of perpendiculars on the rays of the complex.

This elegant theorem is due to TAIT.

We might adopt a more general method of exploration by supposing the rays through the exploring radius to be parallel to a fixed plane. The results thus obtained are very interesting, but we pass over them, simply remarking that in this case the equatorial surface corresponding to the given plane plays the part of (24).

On the Congruency formed by the lines of Single Resultants.

We might regard the congruency of single resultants as the rays common to the complexes of the second and fourth order determined by the relations (5) and (7).

A simpler method will suffice to deduce MINDING'S theorem for the case $f=0$.

Let (xyz) be any point on the ray passing through (abc), we have

$$\lambda_1 = \frac{a-x}{d} \text{ \&c. where } d^2=(x-a)^2+(y-b)^2+(z-c^2)\,,$$

also

$$\lambda_1 = \frac{a-\xi}{a\lambda_1+b\mu_1+c\nu_1}, \text{ \&c.,}$$

$\xi\eta\zeta$ being co-ordinates of the foot of the perpendicular,

and $\quad r^2-\rho^2=(a\lambda_1+b\mu_1+c\nu_1)^2$ where $r^2=a^2+b^2+c^2$.

Hence equations (8) and (9) give us

$$\begin{aligned} f^4\lambda_1^2+g^4\mu_1^2+h^4\nu_1^2 &= \rho^4+f^2(a-\lambda_1\sqrt{r^2-\rho^2})^2 \\ &\quad + \text{\&c.} \\ &\quad + \text{\&c.} \\ &= \rho^4+(f^2\lambda_1^2+g^2\mu_1^2+h^2\nu_1^2)(r^2-\rho^2) \\ &\quad +f^2a^2+g^2b^2+h^2c^2 \\ &\quad -2(f^2a\lambda_1+g^2b\mu_1+h^2c\nu_1)(a\lambda_1+b\mu_1+c\nu_1) \\ &= \rho^4+r^2\rho-\rho^4+\text{\&c.}-\text{\&c.}, \end{aligned}$$

whence

$$\begin{aligned} &f^2(f^2-r^2)\lambda_1^2+g^2(g^2-r^2)\mu_1^2+h^2(h^2-r^2)\nu_1^2 \\ &+2(f^2a\lambda_1+g^2b\mu_1+h^2c\nu_1)(a\lambda_1+b\mu_1+c\nu_1)=f^2a^2+g^2b^2+h^2c^2\,. \quad . \qquad (25) \end{aligned}$$

From (8) we get

$$f^2\lambda_1^2+g^2\mu_1^2+h^2\nu_1^2+(a\lambda_1+b\mu_1+c\nu_1)^2=r^2\,. \quad . \quad . \quad . \qquad (26)$$

The common congruency is of the fourth order.

Equations, (25) and (26), represent quadric cones having their common vertex at (abc). These have in general four generators in common. Hence through the point (abc) there pass in general four rays of the congruency.

Minding's Theorem when $f=0$.

All the rays must cut the plane of yz, let us therefore put $a=0$, and consider where the rays through $(0bc)$ cut the plane of xy. Putting $z=0$, and substituting for $\lambda_1\mu_1\nu_1$, r^2 being now b^2+c^2, we find that, if we restrict ourselves to MINDING's case by putting $f=0$, (25) and (26) become

$$-(g^2b^2+h^2c^2)x^2-(g^2+h^2)c^2y^2+g^4(y-b)^2+h^4c^2=0\,, \quad . \quad . \quad (27)$$

and

$$-r^2x^2-c^2y^2+g^2(y-b)^2+h^2c^2=0\,. \quad . \quad . \quad . \quad (28)$$

(27) and (28) intersects in the points in which the rays through $(0bc)$ cut yz. But, if we multiply (28) by g^2, and subtract (27) from it, we get

$$c^2\{h^2y^2-(g^2-h^2)x^2+h^2(g^2-h^2)\}=0\,. \quad . \quad . \quad . \quad (29)$$

Hence, if c be not $=0$, all the points in which rays cut xy lie on the conic

$$z=0 \quad \frac{x^2}{h^2}-\frac{y^2}{g^2-h^2}=1\,. \quad . \quad . \quad . \quad (30)$$

Similarly, if b be not $=0$, all the points in which rays cut xz lie on the conic

$$y=0 \quad \frac{x^2}{g^2}+\frac{z^2}{g^2-h^2}=1 \quad . \quad . \quad . \quad . \quad (31)$$

It will be found that the cases $c=0$, $b=0$ lead only to particular cases of the general theorem.

The congruency is of the fourth class.

Hence the congruency is identical with the doubly infinite system of rays that intersect the focal conics of the ellipsoid

$$\frac{x^2}{g^2+h^2}+\frac{y^2}{h^2}+\frac{z^2}{g^2}=1\,; \quad . \quad . \quad . \quad (32)$$

it is, therefore, of the fourth class.

Returning to the more general case, if we denote $f^2\xi^2+g^2\eta^2+h^2\zeta^2$ by q^4, (8) and (9) may be written

$$(\rho^2-f^2)\lambda_1^2+(\rho^2-g^2)\mu_1^2+(\rho^2-h^2)\nu_1^2=0 \quad . \quad . \quad . \quad (33)$$

$$(\rho^4+q^4-f^4)\lambda_1^2+(\rho^4+q^4-g^4)\mu_1^2+(\rho^4+q^4-h^4)\nu_1^2=0\,. \quad . \quad . \quad (34)$$

Whence

$$\lambda_1^2=P\{\,\rho^4+q^4-(g^2+h^2)\rho^2+g^2h^2\,\}\,(g^2-h^2)$$

$$\mu_1^2=P\{\,\&\text{c.}\,\}$$

$$\nu_1^2=P\{\,\&\text{c.}\,\}\,. \quad . \quad . \quad . \quad (35)$$

Surface locus of the feet of the perpendiculars on the rays of the congruency.

Hence for the locus of the feet of the perpendicular $(\xi\eta\zeta)$ on a ray of the congruency common to the two complexes (8) and (9) we have the equation

$$\left[\xi^2\{\rho^4+(f^2\xi^2+g^2\eta^2+h^2\zeta^2)-(g^2+h^2)\rho^2+g^2h^2\}(g^2-h^2)\right]^{\frac{1}{2}}$$
$$+\left[\eta^2\{\ \&c. \qquad \right]^{\frac{1}{2}} + \left[\zeta^2\{\ \&c. \qquad \right]^{\frac{1}{2}}=0, \quad . \quad . \qquad (36)$$

which is apparently of the twelfth degree.

Perpendiculars on the four rays having a given direction.

Through a point at an infinite distance in the direction (lmn) four rays of the congruency in general pass. From what has been seen already the perpendiculars on these four are each equal to

$$\sqrt{f^2l^2+g^2m^2+h^2n^2}\,.$$

Locus of feet of perpendiculars on rays parallel to given plane for the two complexes.

The locus of the feet of the perpendiculars on the rays of the first complex, (8) or (33), which are parallel to a given plane is

$$(\rho^2-f^2)(m\zeta-n\eta)^2+(\rho^2-g^2)(n\xi-l\zeta)^2+(\rho^2-h^2)(l\eta-m\xi)^2=0\,. \quad . \qquad (37)$$

The corresponding locus for the second complex, (9) or (34), is

$$\{\rho^4+(f^2\xi^2+g^2\eta^2+h^2\zeta^2)-f^4\}(m\zeta-n\eta)^2$$
$$+\ \&c. \qquad +\ \&c. \qquad =0 \quad . \quad . \quad . \qquad (38)$$

Perpendiculars on rays parallel to a given plane.

The locus of the feet of the perpendiculars on the rays of the common congruency which are parallel to the given plane is the intersection of these two surfaces, a curve, therefore, of the twenty-fourth degree.

Perpendiculars on rays passing through a given line.

The locus of the feet of perpendiculars on the rays that pass through a given line may be found by substituting in (37) and (38)

$$l(\rho^2-a\xi-b\eta-c\zeta)-(\xi-a)\{l(\xi-a)+m(\eta-b)+n(\zeta-c)\}$$

for $\qquad m\zeta-n\eta, \qquad$ and so on.

An endless variety of similar results might easily be given, but we have already sufficiently exemplified the fertility of the methods employed.

(*Added May* 1, 1880.)

Since the above paper was written, I have seen the second part of the German translation of SOMOFF'S "Mechanics." I find there a discussion of MINDING'S System of Forces in which RODRIGUES' co-ordinates are used. A proof of MINDING'S theorem is also given somewhat resembling the second of those given above. SOMOFF, however, looks at the matter almost entirely from the statical point of view, and, as I think that many parts of the foregoing paper have still an interest of their own, I have allowed the whole to stand with a slight addition on page 9.

XIV.—*On the Action of Sulphide of Potassium upon Chloroform.* By W. W. J. Nicol, M.A. Communicated by Professor Crum Brown.

(Received 23d January 1880. Read 2d February 1880.)

In the "Journal für praktische Chemie," [2] 6, 99, Pfankuch states that "when one adds chloroform to an alcoholic solution of sulphide of potassium a reaction takes place often with explosive violence, and by repeated extraction of the mass with absolute alcohol one obtains a compound which crystallises from alcohol in long prisms, and may be considered as a double salt of sulphide of potassium and sulphoform."

On searching for some record of the discovery of sulphoform ($H_2C_2S_3$), I found in the "Journal de Pharmacie," xxiii. 12, that Bouchardat claimed to have prepared sulphoform by the action of iodoform on red sulphide of mercury, and, after describing its properties, stated that he had not confirmed his results by an elementary analysis, and that it appeared to him "that the body so formed retained a certain proportion of iodine the same as chloriodoform, so that the name sulphiodoform would be more suitable than that of sulphoform."

As a great deal of uncertainty seemed to surround this point, I thought that it might be interesting to repeat the experiments of Pfankuch, and if possible to obtain some accurate knowledge of the products of the action of sulphide of potassium on chloroform.

I therefore prepared a quantity of alcoholic sulphide of potassium by dissolving caustic potash in alcohol, dividing the solution into two parts, saturating the one with sulphuretted hydrogen, and then adding the remainder. On mixing a few drops of chloroform in a test-tube with a little of the sulphide of potassium thus prepared, and gently warming, a reaction took place with such violence that the contents of the test-tube were projected to some distance. On repeating the experiment, taking care to add the chloroform in very small portions at a time, the solution boiled violently from the energy of the reaction, and a quantity of chloride of potassium separated out, reminding me of the action of chloroform on alcoholic caustic potash, where chloride and formiate of potassium are produced; and I began to hope that one of the products of this reaction might be thioformic acid (a body analogous to Kekulé's thiacetic acid, where one of the atoms of oxygen in the group COOH is replaced by sulphur), regarding which very little, if anything, is known; the only notices of thioformic acid that I could find being as follows:—

Limpricht, in the "Annalender Chemie und Pharmacie," xcvii. 361, states that during the preparation of formic acid by passing dry sulphuretted hydrogen over dry formiate of lead at a temperature over 100° C., small needle-shaped crystals separated out from the formic acid. These he believed to be thioformic acid (HCOSH), though in favour of this supposition he could only bring forward the sulphur analyses.

I.	II.	Theory for (HCOSH).
51·2 per cent.	52·5 per cent.	51·6 per cent.

He made several unsuccessful attempts to determine the carbon and hydrogen; finding 4 to 7 per cent. too much carbon, and 1·5 to 3 per cent. too much hydrogen. Again, in the "Journal of the Chemical Society," xv. 278, W. J. Hurst states that he repeated the experiments of Limpricht with chiefly negative results. He also obtained crystals in the way described by Limpricht, which on analysis gave results differing both from Limpricht's numbers and from those for theory.

	Theory (HCOSH).	I.	II.	III.
C	19·3	27·9	29·2	28·2
H	3·2	4·7	4·8	5·2
S	51·6	58·7	52·8	56·7
O	25·9			
	100·0			

Hurst assigns no formula to the body he thus obtained, but states positively that "it cannot be thioformic acid."

I then treated the solution obtained by the action of chloroform on sulphide of potassium with mercuric oxide to remove excess of sulphide if any, and if thioformic acid were present to form formic acid by the replacement of sulphur by oxygen; on filtering off the clear liquid and adding acetate of lead a white precipitate was formed which was sparingly soluble in water: this was washed, dried, and the lead estimated as sulphate giving—

69·8 per cent. lead. Theory $\left\{\begin{matrix}\mathrm{HCOO}\\\mathrm{HCOO}\end{matrix}\right\}\mathrm{Pb}$. 69·8 per cent. lead.

I then prepared a large quantity of sulphide of potassium in the manner mentioned above, and placed a little of the alcoholic solution in a flask fitted with an upright condenser; on warming the contents of the flask to about 50° C., and adding small portions of pure chloroform, the reaction took place with such a disengagement of heat that although the flask was cooled in water a portion of the alcohol passed off in vapour smelling strongly of mercaptan or some analogous compound; at the same time chloride of potassium separated out as in the former experiment. When the further addition of chloroform produced no action, the whole was digested for several hours in a water bath, the chloride of potassium was then filtered off, and the clear solution distilled. The greater part came over below 85° C., and smelt strongly of mercaptan, while the last portion consisted of water containing a few oily globules of a dark orange colour and a characteristic odour.

The dark brown residue in the flask was treated with boiling absolute alcohol and filtered. The solution on cooling deposited a number of fine needle-shaped crystals, which were washed with alcohol till perfectly white, then dried; and on examination they were found to contain carbon, sulphur, hydrogen, and potassium. An analysis of the crystals gave the following result :—

Potassium, . .	39·01	39·2
Sulphur, . .	32·2	...

On calculating the percentages of potassium and sulphur for thioformiate of potassium, we find potassium 39·09 per cent., sulphur 31·9 per cent. The potassium was estimated by converting the salt into sulphate by treating it with sulphuric acid. The sulphur was precipitated as barium sulphate after oxidation with nitric acid and chlorate of potassium.

The solution in absolute alcohol was evaporated to a small bulk and allowed to cool, when a second crop of crystals was obtained, which, however, did not become colourless when washed with alcohol. With a view to recrystallisation they were boiled with ordinary proof spirit, when it was found that though soluble in absolute alcohol they did not dissolve in the spirit, but melted, and formed a distinct layer below the liquid. On treatment with successive quantities of spirit, the oily liquid became colourless, and on cooling solidified to an opaque white mass which was dissolved in water. The solution behaved with nitrate of silver like hyposulphite of sodium, forming a white precipitate which, slowly at the ordinary temperature, but rapidly on warming, became yellow, then brown, and ultimately black, owing to the production of sulphide of silver. The solution when acidified with nitric acid remained clear in the cold, but on warming became milky from separation of sulphur, and smelt of formic acid. Another portion, after acidifying in the cold with nitric acid, gave a white precipitate with acetate of lead. The whole was then precipitated as lead salt, and the lead estimated as sulphate.

I.	II.
64·09	64·19 per cent. of lead.

The lead salt giving the above percentage of lead was boiled with a large quantity of water and allowed to crystallise (the undissolved part turned black on continued boiling), crystals soon formed, and on analysis gave—

I.	II.	Theory for $\left\{\begin{matrix}HCOS\\HCOS\end{matrix}\right\}Pb$.
63·3	62·9	63·03 of lead.

An attempt was then made to obtain the free acid. A quantity of the lead salt was suspended in water, and sulphuretted hydrogen passed in in excess on filtering off the sulphide of lead and allowing the clear solution to remain exposed to the air till no sulphuretted hydrogen remained in solution. The liquid was found to be strongly acid, and contained scarcely a trace of HCOSH. While at the same time a large quantity of formic acid was present, recognised by odour and its reducing action on mercuric chloride and nitrate of silver.

This method having failed to give the free acid, the barium salt was prepared by treating a mixture of barium carbonate and the lead salt suspended in water with excess of sulphuretted hydrogen; the solution was evaporated in presence of excess of barium carbonate, filtered, and alcohol added. White pearly scales separated, which were dried and found to contain

53·1 per cent. Ba. Theory, 52·9 per cent. Ba.

From this it appears probable that when the thioformiate of lead is decomposed by H_2S, the thioformic acid decomposes with the formation of formic acid; but if the thioformic acid is set free in the presence of a base, then decomposition does not take place.

There remains only for me to give the probable formulæ for this reaction, which lead to the production of thioformiate of potassium when sulphide of potassium and chloroform act on one another. After the reaction was over, and chloroform was in excess, it was noticed that the solution was strongly alkaline, and contained sulphide or sulphydrate of potassium. In order to determine which of these two salts was present, a little iodide of ethyl was mixed with the liquid and mercaptan was formed; it was also found that alcoholic sulphydrate of potassium would not act on chloroform, while even a very dilute solution of sulphide of potassium acted at once. Any explanation, then, of the reaction must account for the residual sulphydrate. The following give the probable explanation:—

$HCCl_3 + 2K_2S = 3KCl + HCSSK$, this HCSSK comes in contact with water, $HCSSK + H_2O = HCOSK + H_2S$, and $H_2S + K_2S = 2KHS$.

XV.—*A New Method of Investigating Relations between Functions of the Roots of an Equation and its Coefficients.* By J. DOUGLAS HAMILTON DICKSON, M.A., Fellow and Tutor of St Peter's College, Cambridge.

(Received January 6, Read January 19, 1880.)

I. If $ax^n + n.bx^{n-1} + \frac{n.n-1}{1.2}.cx^{n-2} + \ldots = 0$ be a rational equation of the nth degree, NEWTON'S rule for a superior limit to the number of its imaginary roots depends upon the changes of sign in the series of functions—called, by SYLVESTER, Quadratic Elements—

$$a^2,\ b^2 - ac,\ c^2 - bd,\ \ldots .$$

$n+1$ in number.

It is a matter of some interest to know the relations in which the quadratic elements stand to the roots of the equation. The following method exhibits this relationship, and leads to others of a higher class.

For simplicity, consider the biquadratic equation

$$ax^4 + 4bx^3 + 6cx^2 + 4dx + e = 0\,,$$

whose roots are $\alpha,\ \beta,\ \gamma,\ \delta$; and $P_1,\ P_2,\ \ldots .$ are the sums of the roots one at a time, two at a time. . . . . [This system of notation, viz., $a,\ b,\ c,\ \ldots .$; $\alpha,\ \beta,\ \gamma,\ \ldots .$; $P_1,\ P_2,\ \ldots .$; will be continued for equations of higher degrees.]

It is a known result that, for example,

$$\left|\begin{array}{ccc||ccc} l\,, & m\,, & n & L\,, & M\,, & N \\ p\,, & q\,, & r & P\,, & Q\,, & R \end{array}\right| = \Sigma\left\{\left|\begin{array}{cc||cc} l\,, & m & L\,, & M \\ p\,, & q & P\,, & Q \end{array}\right|\right\}\,,$$

and also

$$= \left|\begin{array}{cc} lL + mM + nN\,, & lP + mQ + nR \\ pL + qM + rN\,, & pP + qQ + rR \end{array}\right|$$

and the theorem may be continued to any extent.

The symbol

$$\left|\begin{array}{cccc||cccc} \alpha\,, & \beta\,, & \gamma\,, & \delta & 1\,, & 1\,, & 1\,, & 1 \\ 1\,, & 1\,, & 1\,, & 1 & \beta+\gamma+\delta\,, & \alpha+\gamma+\delta\,, & \alpha+\beta+\delta\,, & \alpha+\beta+\gamma \end{array}\right|$$

$$= \Sigma\left\{\left|\begin{array}{cc||cc} \alpha\,, & \beta & 1\,, & 1 \\ 1\,, & 1 & \beta+\gamma+\delta\,, & \alpha+\gamma+\delta \end{array}\right|\right\} = \Sigma\{(\alpha-\beta)^2\}\,,$$

and also $$= \begin{vmatrix} P_1 , 2P_2 \\ 4P_0 , 3P_1 \end{vmatrix} = 3P_1^2 - 8P_0P_2$$

that is $$48(b^2 - ac) = a^2 . \Sigma\{(\alpha - \beta)^2\} \quad . \quad . \quad . \quad . \quad (1).$$

Again, the symbol

$$\left|\begin{array}{cccc||cccc} \alpha , & \beta , & \gamma , & \delta & \beta+\gamma+\delta , & \alpha+\gamma+\delta , & \alpha+\beta+\delta , & \alpha+\beta+\gamma \\ 1 , & 1 , & 1 , & 1 & \beta\gamma+\beta\delta+\gamma\delta , & \alpha\gamma+\alpha\delta+\gamma\delta , & \alpha\beta+\alpha\delta+\beta\delta , & \alpha\beta+\alpha\gamma+\beta\gamma \end{array}\right|$$

$$= \Sigma\left\{\left|\begin{array}{cc||cc} \alpha , & \beta & \beta+\gamma+\delta , & \alpha+\gamma+\delta \\ 1 , & 1 & \beta\gamma+\beta\delta+\gamma\delta , & \alpha\gamma+\alpha\delta+\gamma\delta \end{array}\right|\right\} = \Sigma\left\{(\alpha-\beta)^2 \begin{vmatrix} \gamma+\delta , & 1 \\ \gamma\delta & , \gamma+\delta \end{vmatrix}\right\}$$

and also $$= \begin{vmatrix} 2P_2 , 3P_3 \\ 3P_1 , 2P_2 \end{vmatrix} = 4P_2^2 - 9P_1P_3$$

that is $$144(c^2 - bd) = a^2 . \Sigma\{(\alpha - \beta)^2(\overline{\gamma+\delta}^{\,2} - \gamma\delta)\} \quad . \quad . \quad (2).$$

Likewise,

$$\left|\begin{array}{cccc||cccc} \alpha , & \beta , & \gamma , & \delta & \beta\gamma+\beta\delta+\gamma\delta , & \alpha\gamma+\alpha\delta+\gamma\delta , & \alpha\beta+\alpha\delta+\beta\delta , & \alpha\beta+\alpha\gamma+\beta\gamma \\ 1 , & 1 , & 1 , & 1 & \beta\gamma\delta , & \alpha\gamma\delta , & \alpha\beta\delta , & \alpha\beta\gamma \end{array}\right|$$

$$= \Sigma\left\{\left|\begin{array}{cc||cc} \alpha , & \beta & \beta\gamma+\beta\delta+\gamma\delta , & \alpha\gamma+\alpha\delta+\gamma\delta \\ 1 , & 1 & \beta\gamma\delta , & \alpha\gamma\delta \end{array}\right|\right\} = \Sigma\left\{(\alpha-\beta)^2 \begin{vmatrix} \gamma\delta , & \gamma+\delta \\ 0 , & \gamma\delta \end{vmatrix}\right\}$$

and also $$= \begin{vmatrix} 3P_3 , 4P_4 \\ 2P_2 , P_3 \end{vmatrix} = 3P_3^2 - 8P_2P_4$$

that is $$48(d^2 - ce) = a^2 . \Sigma\{(\alpha - \beta)^2 . \gamma^2\delta^2\} \quad . \quad . \quad . \quad . \quad (3).$$

The last result might have been obtained from that for $b^2 - ac$ by considering the roots $\frac{1}{\alpha}, \frac{1}{\beta}, \frac{1}{\gamma}, \frac{1}{\delta}$; in which case it would have appeared in the form $\Sigma\{(\alpha\gamma\delta - \beta\gamma\delta)^2\}$.

In an equation of the fifth degree the results are similar.

[For an equation of the nth degree, we have always $n^2(n-1)(b^2 - ac) = a^2 . \Sigma\{(\alpha - \beta)^2\}$].

As an example from the fifth degree, take the following case.

The symbol

$$\left|\begin{array}{ccccc||cccc} \alpha , & \beta , & \gamma , & \delta , & \epsilon & \beta\gamma+\beta\delta+\beta\epsilon+\gamma\delta+\gamma\epsilon+\delta\epsilon , & \alpha\gamma+\alpha\delta+\alpha\epsilon+\gamma\delta+\gamma\epsilon+\delta\epsilon , & \ldots\ldots , & \ldots\ldots ; \ldots\ldots \\ 1 , & 1 , & 1 , & 1 , & 1 & \beta\gamma\delta+\beta\gamma\epsilon+\beta\delta\epsilon+\gamma\delta\epsilon , & \alpha\gamma\delta+\alpha\gamma\epsilon+\alpha\delta\epsilon+\gamma\delta\epsilon & , \ldots\ldots , & \ldots\ldots ; \ldots\ldots \end{array}\right| \quad (4)$$

$$=\Sigma\left\{(\alpha-\beta)^2\begin{vmatrix}\gamma\delta+\gamma\epsilon+\delta\epsilon\ , & \gamma+\delta+\epsilon\\ \gamma\delta\epsilon\ , & \gamma\delta+\gamma\epsilon+\delta\epsilon\end{vmatrix}\right\}$$

and also
$$=\begin{vmatrix}3\mathrm{P}_3\ , & 4\mathrm{P}_4\\ 3\mathrm{P}_2\ , & 2\mathrm{P}_3\end{vmatrix}=6\mathrm{P}_3^2-12\mathrm{P}_2\mathrm{P}_4$$

that is
$$600(d^2-ce)=a^2\Sigma\left\{(\alpha-\beta)^2\left(\overline{\gamma\delta+\gamma\epsilon+\delta\epsilon}^{\,2}-\overline{\gamma+\delta+\epsilon}.\gamma\delta\epsilon\right)\right\}.$$

The results for the equation of the fifth degree are

$$\begin{aligned}100(b^2-ac)&=a^2.\Sigma\{(\alpha-\beta)^2\}\\ 600(c^2-bd)&=a^2.\Sigma\{(\alpha-\beta)^2(\mathrm{Q}_1^2-\mathrm{Q}_0\mathrm{Q}_2)\}\\ 600(d^2-ce)&=a^2.\Sigma\{(\alpha-\beta)^2(\mathrm{Q}_2^2-\mathrm{Q}_1\mathrm{Q}_3)\}\\ 100(e^2-df)&=a^2.\Sigma\{(\alpha-\beta)^2(\mathrm{Q}_3^2-\mathrm{Q}_2\mathrm{Q}_4)\}\\ &=a^2.\Sigma\{(\alpha-\beta)^2.\gamma^2\delta^2\epsilon^2\}\ ,\qquad\text{since } \mathrm{Q}_4=0\ ,\quad(5),\end{aligned}$$

where Q_m is interpreted to be the sum of the products m at a time of all the roots of the given equation, other than those in the squared difference of roots with which it is associated, and $\mathrm{Q}_0=1$.

Hence each quadratic element consists of $\frac{n.n-1}{1.2}$ terms: and each term consists of two factors;—the one being the square of the difference of a pair of roots, and the other a function of all the remaining roots.

Let the symbol of roots (4) last discussed be denoted by $f(3)$, 3 being the dimensions of the second line of the second matrix; then in an equation of the nth degree

$$f(m)=\begin{vmatrix}m.\mathrm{P}_m\ , & m+1.\mathrm{P}_{m+1}\\ n-m+1.\mathrm{P}_{m-1}\ , & n-m.\mathrm{P}_m\end{vmatrix},$$

and if

$$\nu=\frac{n.n-1.\ \ldots.\ n-m+1}{1.2\ \ldots\ldots\ .m},$$

$$\mathrm{P}_{m-1}=\nu\frac{m}{n-m+1}\cdot\frac{r}{a},$$

$$\mathrm{P}_m=\nu\cdot\frac{s}{a},$$

$$\mathrm{P}_{m+1}=\nu\frac{n-m}{m+1}\cdot\frac{t}{a},$$

we have

$$f(m)=\nu^2.n-m.m\frac{s^2-rt}{a^2}\cdot$$

Thus, when $n=6$, the successive f's have the numerical factors 180, 1800, 3600, 1800, 180.

In reducing the second factor of one of the terms under a Σ,—take an example from equation (2),—the process was as follows :—

1. Subtract the first column from the second,—thus, all terms in the second column which contain neither α nor β are removed, and what remains contains $\alpha-\beta$ as a factor.
2. *Now* divide the second column by $\alpha-\beta$. It is thus reduced one degree lower than the first, and does not contain β, but only terms which when multiplied by β and subtracted from the first column leave those original terms of the first column which do not contain β.

Hence such a factor as that considered is always (1) divisible by $\alpha-\beta$; and (2) after the above two operations contains neither α nor β.

This process is general, and gives for an equation of the nth degree

$$a^2.f(m)=\nu^2.n-m.m.(s^2-rt)=a^2.\Sigma\{(\alpha-\beta)^2(Q^2_{m-1}-Q_{m-2}Q_m)\} \quad . \qquad (6).$$

If the roots of the equation are all real, the functions $f(m)$ are all positive.

For ; the expression $Q^2_{m-1}-Q_{m-2}Q_m$ contains only real roots, therefore (as it may be written, changing the notation)

$$P^2_{m-1}-P_{m-2}P_m \text{ is } \textit{a fortiori} \text{ positive if } P^2_{m-1}-\frac{n-m}{m-1}\,\frac{m}{n-m-1}\,P_{m-2}P_m$$

is positive ; but this is, *á un facteur près* $f(m-1)$ for an equation of the $(n-2)$th degree with all its roots real. Thus, finally $Q^2_{m-1}-Q_{m-2}Q_m$ is positive if $f(1)$, or $f(r)$ is positive in an equation of the rth degree, r being one of the numbers $n,\ n-2,\ n-4,\ \ldots \left.\begin{matrix}2\\1\end{matrix}\right\}$ according as n is $\left\{\begin{matrix}\text{even.}\\\text{odd.}\end{matrix}\right.$ But in such a case $f(1)$ and $f(r)$ are positive. Hence $f(m)$ is positive always, when the roots are real.

Hence Newton's quadratic elements are always positive when the roots of the equation are real.

This supplies the desideratum mentioned by Sylvester, "Proc. Lond. Math. Soc." vol. i. p. 13, note.

II. The results thus obtained may be condensed as follows :—

We may write

$$\left|\begin{matrix}\alpha\,,\ \beta\,,\ \gamma\,,\ \delta\\ 1\,,\ 1\,,\ 1\,,\ 1\end{matrix}\right\| \begin{matrix}1 & , & 1 & , & 1 & , & 1\\ \beta+\gamma+\delta & , & \alpha+\gamma+\delta & , & \alpha+\beta+\delta & , & \alpha+\beta+\gamma\\ \beta\gamma+\beta\delta+\gamma\delta & , & \alpha\gamma+\alpha\delta+\gamma\delta & , & \alpha\beta+\alpha\delta+\beta\delta & , & \alpha\beta+\alpha\gamma+\beta\gamma\\ \beta\gamma\delta & , & \alpha\gamma\delta & , & \alpha\beta\delta & , & \alpha\beta\gamma\end{matrix}\right|$$

$$=\Sigma\left\{(\alpha-\beta)\left|\begin{matrix}1 & , & 1\\ \beta+\gamma+\delta & , & \alpha+\gamma+\delta\\ \beta\gamma+\beta\delta+\gamma\delta & , & \alpha\gamma+\alpha\delta+\gamma\delta\\ \beta\gamma\delta & , & \alpha\gamma\delta\end{matrix}\right|\right\}=\Sigma\left\{(\alpha-\beta)^2\left|\begin{matrix}1 & , & 0\\ \gamma+\delta & , & 1\\ \gamma\delta & , & \gamma+\delta\\ 0 & , & \gamma\delta\end{matrix}\right|\right\},$$

and also
$$= \begin{vmatrix} P_1 , & 2P_2 , & 3P_3 , & 4P_4 \\ 4P_0 , & 3P_1 , & 2P_2 , & P_3 \end{vmatrix} ,$$

that is

$$\begin{array}{r|cccc|} & 1 , & -3 , & 3 , & -1 \\ \hline -4 & b , & c , & d , & e \\ 4 & a , & b , & c , & d \end{array} = a^2 . \Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} 1 , & 0 \\ \gamma+\delta , & 1 \\ \gamma\delta , & \gamma+\delta \\ 0 , & \gamma\delta \end{vmatrix} \right\} .$$

Hence the following $\left(\frac{4 . 3}{1 . 2}=\right)$ 6 results for biquadratic—the first three being NEWTON's quadratic elements—

$$48(b^2-ac) = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} 1 , & 0 \\ \gamma+\delta , & 1 \end{vmatrix} \right\} = a^2\Sigma \{(\alpha-\beta)^2\} ,$$

$$144(c^2-bd) = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} \gamma+\delta , & 1 \\ \gamma\delta , & \gamma+\delta \end{vmatrix} \right\} = a^2\Sigma \{(\alpha-\beta)^2(\overline{\gamma+\delta}^{\,2}-\gamma\delta)\} ,$$

$$48(d^2-ce) = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} \gamma\delta , & \gamma+\delta \\ 0 , & \gamma\delta \end{vmatrix} \right\} = a^2\Sigma \{(\alpha-\beta)^2\gamma^2\delta^2\} ,$$

and,

$$-48(bc-ad) = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} 1 , & 0 \\ \gamma\delta , & \gamma+\delta \end{vmatrix} \right\} = a^2\Sigma \{(\alpha-\beta)^2(\gamma+\delta)\} ,$$

$$16(bd-ae) = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} 1 , & 0 \\ 0 , & \gamma\delta \end{vmatrix} \right\} = a^2\Sigma \{(\alpha-\beta)^2\gamma\delta\} ,$$

$$-48(cd-be) = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} \gamma+\delta , & 1 \\ 0 , & \gamma\delta \end{vmatrix} \right\} = a^2\Sigma \{(\alpha-\beta)^2(\gamma+\delta)\gamma\delta\} .$$

The equation of the fifth degree gives similarly, the $\left(\frac{5 . 4}{1 . 2}=\right)$10 results

$$\begin{array}{r|cccccc|} & 1 , & -4 , & 6 , & -4 , & 1 & \\ \hline -5 & b , & c , & d , & e , & f & \\ 5 & a , & b , & c , & d , & e & \end{array} = a^2\Sigma \left\{ (\alpha-\beta)^2 \begin{vmatrix} 1 , & 0 \\ \gamma+\delta+\epsilon , & 1 \\ \gamma\delta+\gamma\epsilon+\delta\epsilon , & \gamma+\delta+\gamma \\ \gamma\delta\epsilon , & \gamma\delta+\gamma\epsilon+\delta\epsilon \\ 0 , & \gamma\delta\epsilon \end{vmatrix} \right\} ,$$

and that of the sixth degree the $\left(\frac{6 . 5}{1 . 2}=\right)$15 results

$$\begin{array}{r|cccccc|} & 1, & -5, & 10, & -10, & 5, & -1 \\ \cline{2-7} -6 & b, & c, d, & e, & f, & g & \\ 6 & a, & b, c, & d, & e, & f & \end{array} = \alpha^2\Sigma\left\{(\alpha-\beta)^2 \left|\begin{array}{cc} 1, & 0 \\ \gamma+\delta+\epsilon+\zeta, & 1 \\ \gamma\delta+\gamma\epsilon+\gamma\zeta+\delta\epsilon+\delta\zeta+\epsilon\zeta, & \gamma+\delta+\epsilon+\zeta \\ \gamma\delta\epsilon+\gamma\delta\zeta+\gamma\epsilon\zeta+\delta\epsilon\zeta & ,\gamma\delta+\gamma\epsilon+\gamma\zeta+\delta\epsilon+\delta\zeta+\epsilon\zeta \\ \gamma\delta\epsilon\zeta, & \gamma\delta\epsilon+\gamma\delta\zeta+\gamma\epsilon\zeta+\delta\epsilon\zeta \\ 0, & \gamma\delta\epsilon\zeta \end{array}\right|\right\} \quad (7).$$

III. To extend this method, I write, for example, the symbol—

$$\left|\begin{array}{cccc} \alpha^2, & \beta^2, & \gamma^2, & \delta^2 \\ \alpha, & \beta, & \gamma, & \delta \\ 1, & 1, & 1, & 1 \end{array}\right\| \left.\begin{array}{cccc} 1, & 1, & 1, & 1 \\ \beta+\gamma+\delta, & \alpha+\gamma+\delta, & \alpha+\beta+\delta, & \alpha+\beta+\gamma \\ \beta\gamma+\beta\delta+\gamma\delta, & \alpha\gamma+\alpha\delta+\gamma\delta, & \alpha\beta+\alpha\delta+\beta\delta, & \alpha\beta+\alpha\gamma+\beta\gamma \\ \beta\gamma\delta, & \alpha\gamma\delta, & \alpha\beta\delta, & \alpha\beta\gamma \end{array}\right|$$

understanding by it that only *three* horizontal lines from the second (the square) matrix are to be used at once. The resulting determinants are respectively equal to

$$\Sigma\left\{\left|\begin{array}{ccc} \alpha^2, & \beta^2, & \gamma^2 \\ \alpha, & \beta, & \gamma \\ 1, & 1, & 1 \end{array}\right\| \left.\begin{array}{ccc} 1, & 1, & 1 \\ \beta+\gamma+\delta, & \alpha+\gamma+\delta, & \alpha+\beta+\delta \\ \beta\gamma+\beta\delta+\gamma\delta, & \alpha\gamma+\alpha\delta+\gamma\delta, & \alpha\beta+\alpha\delta+\beta\delta \\ \beta\gamma\delta, & \alpha\gamma\delta, & \alpha\beta\delta \end{array}\right|\right\}$$

$$=\Sigma\left\{(\alpha-\beta)^2(\alpha-\gamma)^2(\beta-\gamma)^2.\left|\begin{array}{ccc} 1, & 0, & 0 \\ \delta, & 1, & 0 \\ 0, & \delta, & 1 \\ 0, & 0, & \delta \end{array}\right|\right\}$$

This also is equal to

$$\left|\begin{array}{cccc} P_1P_1-2P_2, & P_1P_2-3P_3, & P_1P_3-4P_4, & P_1P_4 \\ P_1, & 2P_2, & 3P_3, & 4P_4 \\ 4P_0, & 3P_1, & 2P_2, & P_3 \end{array}\right|,$$

where those three columns alone are to be considered at one time, which correspond to the three lines considered at first. This may be written

$$\left|\begin{array}{ccccc} P_1, & 2P_2, & 3P_3, & 4P_4, & 0 \\ P_0, & P_1, & P_2, & P_3, & P_4 \\ ., & P_1, & 2P_2, & 3P_3, & 4P_4 \\ ., & 4P_0, & 3P_1, & 2P_2, & P_3 \end{array}\right|$$

Hence the four equations—

$$a^4\Sigma\left\{(\alpha-\beta)^2(\alpha-\gamma)^2(\beta-\gamma)^2\left|\begin{array}{l} 1\,,\,0\,,\,0 \\ \delta\,,\,1\,,\,0 \\ 0\,,\,\delta\,,\,1 \\ 0\,,\,0\,,\,\delta \end{array}\right|\right\} = \left|\begin{array}{rrrrr} -4b\,, & 12c\,, & -12d\,, & 4e\,, & \cdot \\ a\,, & -4b\,, & 6c\,, & -\ 4d\,, & e \\ \cdot\,, & -4b\,, & 12c\,, & -12d\,, & 4e \\ \cdot\,, & 4a\,, & -12b\,, & 12c\,, & -4d \end{array}\right|\,;$$

or, more symmetrically,

$$a^4\Sigma\left\{(\alpha-\beta)^2(\alpha-\gamma)^2(\beta-\gamma)^2\left|\begin{array}{l} 1\,,\,0\,,\,0 \\ \delta\,,\,1\,,\,0 \\ 0\,,\,\delta\,,\,1 \\ 0\,,\,0\,,\,\delta \end{array}\right| = \begin{array}{r|ccccc|} & + & - & + & - & + \\ -4 & b\,, & 3c\,, & 3d\,, & e\,, & \cdot \\ 1 & a\,, & 3b\,, & 3c\,, & d\,, & \cdot \\ 4 & \cdot\,, & b\,, & 3c\,, & 3d\,, & e \\ -4 & \cdot\,, & a\,, & 3b\,, & 3c\,, & d \end{array}\right\} \quad . \quad (8),$$

the signs and numerical multipliers of each column and line on the right hand side being written respectively above and to the left of them.

Write these four equations, for a moment, thus—

$$\begin{aligned} A\alpha^3 + B\beta^3 + C\gamma^3 + D\delta^3 &= \Delta_3 \\ A\alpha^2 + B\beta^2 + C\gamma^2 + D\delta^2 &= \Delta_2 \\ A\alpha + B\beta + C\gamma + D\delta &= \Delta_1 \\ A + B + C + D &= \Delta_0\,, \end{aligned}$$

multiply them respectively by $4b$, $6c$, $4d$, e , and add : then

$$-a(A\alpha^4 + B\beta^4 + C\gamma^4 + D\delta^4) = \left|\begin{array}{rrrrr} \cdot\,, & -\ 4b\,, & 6c\,, & -\ 4d\,, & e \\ -4b\,, & 12c\,, & -12d\,, & 4e\,, & \cdot \\ a\,, & -\ 4b\,, & 6c\,, & -\ 4d & e \\ \cdot\,, & -\ 4b\,, & 12c\,, & -12d\,, & 4e \\ \cdot\,, & 4a\,, & -12b\,, & 12c\,, & -4d \end{array}\right|$$

that is $$a^4\Sigma\{(\alpha-\beta)^2(\alpha-\gamma)^2(\beta-\gamma)^2\delta^4\} = \left|\begin{array}{rrrr} 12c\,, & -12d\,, & 4e\,, & \cdot \\ -\ 4b\,, & 6c\,, & -\ 4d\,, & e \\ -\ 4b\,, & 12c\,, & -12d\,, & 4e \\ 4a\,, & -12b\,, & 12c\,, & -4d \end{array}\right|$$

$$= \begin{array}{r|cccc|} & - & + & - & + \\ -4 & 3c\,, & 3d\,, & e\,, & \cdot \\ 1 & 3b\,, & 3c\,, & d\,, & \cdot \\ 4 & b\,, & 3c\,, & 3d\,, & e \\ -4 & a\,, & 3b\,, & 3c\,, & d \end{array} \quad . \quad . \quad . \quad (9),$$

thus completing the set of five equations for a biquadratic.

IV. It is noticed in what has gone before that, of the two matrices employed in any symbol of roots, the one refers more particularly to powers (and their sums) of roots, while the other refers to products of roots. Hence, using the principle of multiplication of matrices, I write, for example, the equation

$$\left|\begin{array}{llll} \alpha^4 , & \beta^4 , & \gamma^4 , & \delta^4 \\ \alpha^3 , & \beta^3 , & \gamma^3 , & \delta^3 \\ \alpha^2 , & \beta^2 , & \gamma^2 , & \delta^2 \\ \alpha , & \beta , & \gamma , & \delta \\ 1 , & 1 , & 1 , & 1 \end{array}\right\| \begin{array}{cccc} 1 , & 1 , & 1 , & 1 \\ \beta+\gamma+\delta , & \alpha+\gamma+\delta , & \alpha+\beta+\delta , & \alpha+\beta+\gamma \\ \beta\gamma+\beta\delta+\gamma\delta , & \alpha\gamma+\alpha\delta+\gamma\delta , & \alpha\beta+\alpha\delta+\beta\delta , & \alpha\beta+\alpha\gamma+\beta\gamma \\ \beta\gamma\delta , & \alpha\gamma\delta , & \alpha\beta\delta , & \alpha\beta\gamma \\ & & & \end{array}\right| ,$$

$$=\left|\begin{array}{llll} s_3\mathrm{P}_1-s_2\mathrm{P}_2+s_1\mathrm{P}_3-s_0\mathrm{P}_4 , & s_3\mathrm{P}_2-s_2\mathrm{P}_3+s_1\mathrm{P}_4 , & s_3\mathrm{P}_3-s_2\mathrm{P}_4 , & s_3\mathrm{P}_4 \\ s_2\mathrm{P}_1-s_1\mathrm{P}_2+s_0\mathrm{P}_3 & , s_2\mathrm{P}_2-s_1\mathrm{P}_3+s_0\mathrm{P}_4 , & s_2\mathrm{P}_3-s_1\mathrm{P}_4 , & s_2\mathrm{P}_4 \\ s_1\mathrm{P}_1-s_0\mathrm{P}_2 & , s_1\mathrm{P}_2-s_0\mathrm{P}_3 & , s_1\mathrm{P}_3-s_0\mathrm{P}_4 , & s_1\mathrm{P}_4 \\ s_0\mathrm{P}_1 & , s_0\mathrm{P}_2 & , s_0\mathrm{P}_3 & , s_0\mathrm{P}_4 \\ 4\,\mathrm{P}_0 & , 3\,\mathrm{P}_1 & , 2\,\mathrm{P}_2 & , \mathrm{P}_3 \end{array}\right| ,$$

—where $s_n-s_{n-1}\mathrm{P}_1+s_{n-2}\mathrm{P}_3- \ldots \pm s_0\mathrm{P}_n=0$, and s_n=sum of nth powers of the roots of the equation, except when $n=0$, in which case s_0 is the same as the suffix of the P with which it is associated—in the symbolical form

$$\begin{array}{c|c|} \mathrm{S} & \mathrm{P} \\ \hline 4 & 0 \\ 3 & 1 \\ 2 & 2 \\ 1 & 3 \\ 0 & \end{array} = \left|\begin{array}{llll} s_3 , & s_2 , & s_1 , & s_0 \\ s_2 , & s_1 , & s_0 , & . \\ s_1 , & s_0 , & . , & . \\ s_0 , & . , & . , & . \\ s_{-1} , & . , & . , & . \end{array}\right\| \begin{array}{llll} \mathrm{P}_1 , & -\mathrm{P}_2 , & \mathrm{P}_3 , & -\mathrm{P}_4 \\ \mathrm{P}_2 , & -\mathrm{P}_3 , & \mathrm{P}_4 , & . \\ \mathrm{P}_3 , & -\mathrm{P}_4 , & . , & . \\ \mathrm{P}_4 , & . , & . , & . \\ & & & \end{array}\right| \quad . \quad . \quad . \quad (10),$$

Example: take, in the case of a biquadratic,

$$\begin{array}{c|c|} \mathrm{S} & \mathrm{P} \\ \hline 7 & 0 \\ 5 & 1 \\ 3 & 2 \\ & 3 \end{array} = \left|\begin{array}{lllllll} s_6 , & s_5 , & s_4 , & s_3 , & s_2 , & s_1 , & s_0 \\ s_4 , & s_3 , & s_2 , & s_1 , & s_0 , & . , & . \\ s_2 , & s_1 , & s_0 , & . , & . , & . , & . \\ & & & & & & \end{array}\right\| \begin{array}{llll} \mathrm{P}_1 , & -\mathrm{P}_2 , & \mathrm{P}_3 , & -\mathrm{P}_4 \\ \mathrm{P}_2 , & -\mathrm{P}_3 , & \mathrm{P}_4 , & . \\ \mathrm{P}_3 , & -\mathrm{P}_4 , & . , & . \\ \mathrm{P}_4 , & . , & . , & . \end{array}\right| \quad . \quad . \quad . \quad (11),$$

$$=\left|\begin{array}{llll} s_6\mathrm{P}_1-s_5\mathrm{P}_2+s_4\mathrm{P}_3-s_3\mathrm{P}_4 , & s_6\mathrm{P}_2-s_5\mathrm{P}_3+s_4\mathrm{P}_4 , & s_6\mathrm{P}_3-s_5\mathrm{P}_4 , & s_6\mathrm{P}_4 \\ s_4\mathrm{P}_1-s_3\mathrm{P}_2+s_2\mathrm{P}_3-s_1\mathrm{P}_4 , & s_4\mathrm{P}_2-s_3\mathrm{P}_3+s_2\mathrm{P}_4 , & s_4\mathrm{P}_3-s_3\mathrm{P}_4 , & s_4\mathrm{P}_4 \\ s_2\mathrm{P}_1-s_1\mathrm{P}_2+s_0\mathrm{P}_3 & , s_2\mathrm{P}_2-s_1\mathrm{P}_3+s_0\mathrm{P}_4 , & s_2\mathrm{P}_3-s_1\mathrm{P}_4 , & s_2\mathrm{P}_4 \end{array}\right| \quad . \quad . \quad (11').$$

The left hand side of this equation, in terms of the roots, is

$$=\Sigma\left\{\left|\begin{array}{c}\alpha^7\,,\ \beta^7\,,\ \gamma^7\\ \alpha^5\,,\ \beta^5\,,\ \gamma^5\\ \alpha^3\,,\ \beta^3\,,\ \gamma^3\\ \\ \end{array}\right\|\begin{array}{cc}1 & ,\ldots,\ldots\\ \beta+\ \gamma+\delta & ,\ldots,\ldots\\ \beta\gamma+\beta\delta+\gamma\delta & ,\ldots,\ldots\\ \beta\gamma\delta & ,\ldots,\ldots\end{array}\right|\right\},$$

$$=\Sigma\alpha^3\beta^3\gamma^3(\alpha^2-\beta^2)(\alpha^2-\gamma^2)(\beta^2-\gamma^2).(\alpha-\beta)(\alpha-\gamma)(\beta-\gamma)\left|\begin{array}{c}1\,,\ 0\,,\ 0\\ \delta\,,\ 1\,,\ 0\\ 0\,,\ \delta\,,\ 1\\ 0\,,\ 0\,,\ \delta\end{array}\right|\Bigg\}:$$

for instance, the equation got by omitting the line $\left|\begin{array}{c}\mathrm{P}\\ 1\end{array}\right|$ is, after slight simplification,

$$\Sigma\{\alpha^3\beta^3\gamma^3\delta^2(\alpha^2-\beta^2)(\alpha^2-\gamma^2)(\beta^2-\gamma^2)(\alpha-\beta)(\alpha-\gamma)(\beta-\gamma)\}=\mathrm{P}_3\mathrm{P}_4^2\left|\begin{array}{c}s_6\,,\ s_5\,,\ s_4\\ s_4\,,\ s_3\,,\ s_2\\ s_2\,,\ s_1\,,\ 3\end{array}\right|-\mathrm{P}_4{}^3\left|\begin{array}{c}s_6\,,\ s_5\,,\ s_3\\ s_4\,,\ s_3\,,\ s_1\\ s_2\,,\ s_1\,,\ 0\end{array}\right| \quad (12),$$

and that got by omitting the line $\left|\begin{array}{c}\mathrm{P}\\ 0\end{array}\right|$ is

$$\Sigma\{\alpha^3\beta^3\gamma^3\delta^3(\alpha^2-\beta^2)(\alpha^2-\gamma^2)(\beta^2-\gamma^2)(\alpha-\beta)(\alpha-\gamma)(\beta-\gamma)\}=\mathrm{P}_4^3\left|\begin{array}{c}s_6\,,\ s_5\,,\ s_4\\ s_4\,,\ s_3\,,\ s_2\\ s_2\,,\ s_1\,,\ 4\end{array}\right|,$$

or

$$\Sigma\{\alpha-\beta)^2(\alpha-\gamma)^2(\beta-\gamma)^2.(\alpha+\beta)(\alpha+\gamma)(\beta+\gamma)\}=\left|\begin{array}{c}s_6\,,\ s_5\,,\ s_4\\ s_4\,,\ s_3\,,\ s_2\\ s_2\,,\ s_1\,,\ 4\end{array}\right| \quad (13).$$

This last one is easily verified; for, the determinant

$$=\left|\begin{array}{c}\alpha^4\,,\ \beta^4\,,\ \gamma^4\,,\ \delta^4\\ \alpha^2\,,\ \beta^2\,,\ \gamma^2\,,\ \delta^2\\ 1\ ,\ 1\ ,\ 1\ ,\ 1\end{array}\right\|\begin{array}{c}\alpha^2\,,\ \beta^2\,,\ \gamma^2\,,\ \delta^2\\ \alpha\ ,\ \beta\ ,\ \gamma\ ,\ \delta\\ 1\ ,\ 1\ ,\ 1\ ,\ 1\end{array}\right|$$

$$=\Sigma\{(\overline{\alpha^2-\beta^2}.\overline{\alpha^2-\gamma^2}.\overline{\beta^2-\gamma^2})(\overline{\alpha-\beta}.\overline{\alpha-\gamma}.\overline{\beta-\gamma})\}.$$

V. We may combine matrices of other forms. For example, in a biquadratic—

$$\left|\begin{array}{c}\alpha\beta\,,\ \alpha\gamma\,,\ \alpha\delta\,,\ \beta\gamma\,,\ \beta\delta\,,\ \gamma\delta\\ 1\ ,\ 1\ ,\ 1\ ,\ 1\ ,\ 1\ ,\ 1\end{array}\right\|\begin{array}{c}\gamma\delta\ ,\ \beta\delta\ ,\ \beta\gamma\ ,\ \alpha\delta\ ,\ \alpha\gamma\ ,\ \alpha\beta\\ \alpha\beta\gamma\delta\,,\ \alpha\beta\gamma\delta\,,\ \alpha\beta\gamma\delta\,,\ \alpha\beta\gamma\delta\,,\ \alpha\beta\gamma\delta\,,\ \alpha\beta\gamma\delta\end{array}\right|,$$

$$=\left|\begin{array}{c}6\mathrm{P}_4\,,\ \mathrm{P}_2\mathrm{P}_4\\ \mathrm{P}_2\,,\ 6\mathrm{P}_4\end{array}\right|=36\mathrm{P}_4^2-\mathrm{P}_2^2\mathrm{P}_4$$

and also $$=\Sigma\{(\alpha\beta-\alpha\gamma)(\gamma\delta-\beta\delta).\alpha\beta\gamma\delta\} \quad . \quad . \quad . \quad (14),$$

which *appears* to reduce to, $-P_4\Sigma\{(\alpha-\beta)^2\gamma\delta\}$. This, however, containing only 6 terms, is but part of the true sum, which contains $\left(\frac{6\,.\,5}{1\,.\,2}=\right)$15 terms.

On expansion, we find

$$\Sigma\{(\alpha\beta-\alpha\gamma)(\gamma\delta-\beta\delta)\}=-2\Sigma\{(\alpha-\beta)^2\gamma\delta\}-\Sigma\{(\alpha\beta-\gamma\delta)^2\},$$

the 15 terms being, a set of six terms in $\Sigma\{(\alpha-\beta)^2\gamma\delta\}$ twice over, and a set of three squares in $\Sigma\{(\alpha\beta-\gamma\delta)^2\}$.

Now, $$\left|\begin{array}{cccc}\alpha\,, & \beta\,, & \gamma\,, & \delta \\ 1\,, & 1\,, & 1\,, & 1\end{array}\right\|\left.\begin{array}{cccc}1\,, & 1\,, & 1\,, & 1 \\ \beta\gamma\delta\,, & \alpha\gamma\delta\,, & \alpha\beta\delta\,, & \alpha\beta\gamma\end{array}\right|=\Sigma\{(\alpha-\beta)^2\gamma\delta\}$$

and also $$=\left|\begin{array}{cc}P_1\,, & 4P_4 \\ 4\,, & P_3\end{array}\right|=P_1P_3-16P_4$$

Hence, dividing by P_4 (which, but for symmetry, might have been left out from the first), we have

$$(\alpha\beta-\gamma\delta)^2+(\alpha\gamma-\beta\delta)^2+(\alpha\delta-\beta\gamma)^2=P_2^2-2P_1P_3-4P_0P_4$$
$$=\frac{36c^2-32bd-4ae}{a^2} \quad . \quad . \quad (15).$$

Cor. 1. Hence, from results in II.,

$$4a^2\Sigma\{(\alpha\beta-\gamma\delta)^2\}=144(c^2-bd)+16(bd-ae)$$
$$=a^2\Sigma\{(\alpha-\beta)^2(\gamma+\delta)^2\},$$

verifying the above equation.

Cor. 2. One of MACLAURIN'S conditions for imaginary roots is

$$P_2^2<2P_1P_3+4P_0P_4$$

or, in $$(a',\,b',\,c',\,d',\,e')(x,\,1)^4, \qquad c'^2<2b'd'+4a'e' \quad . \quad . \quad (16).$$

VI. The results arrived at may, in the case of a sextic, be written in the following forms:*

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* I have to thank Professor CAYLEY for valuable suggestions, in accordance with which the notation on the left hand sides of these equations was made to harmonise with that on the right hand sides. This will be seen more fully in the next section.

the first set of equations is,

$$\Sigma\{\zeta(\alpha\beta)\,.\left|\begin{array}{cccccc}1, & [\gamma], & [\gamma\delta], & [\gamma\delta\epsilon], & [\gamma\delta\epsilon\zeta], & 0\\ 0, & 1, & [\gamma], & [\gamma\delta], & [\gamma\delta\epsilon], & [\gamma\delta\epsilon\zeta]\end{array}\right|\}=\begin{array}{r|cccccc|} & 1, & -5, & 10, & -10, & 5, & -1\\ \hline -6 & b, & c, & d, & e, & f, & g\\ 6 & a, & b, & c, & d, & e, & f\end{array},$$

$$\text{or}\qquad =\begin{array}{r|cccccc|} & + & - & + & - & + & -\\ -6 & b, & 5c, & 10d, & 10e, & 5f, & g\\ 6 & a, & 5b, & 10c, & 10d, & 5e, & f\end{array};$$

the second set is,

$$\Sigma\{\zeta(\alpha\beta\gamma)\,.\left|\begin{array}{cccccc}1, & [\delta], & [\delta\epsilon], & [\delta\epsilon\zeta], & ., & .\\ ., & 1, & [\delta], & [\delta\epsilon], & [\delta\epsilon\zeta], & .\\ ., & ., & 1, & [\delta], & [\delta\epsilon], & [\delta\epsilon\zeta]\end{array}\right|\}=\begin{array}{r|ccccccc|} & + & - & + & - & + & - & +\\ -6 & b, & 5c, & 10d, & 10e, & 5f, & g, & .\\ 1 & a, & 5b, & 10c, & 10d, & 5e, & f, & .\\ 6 & ., & b, & 5c, & 10d, & 10e, & 5f, & g\\ -6 & ., & a, & 5b, & 10c, & 10d, & 5e, & f\end{array};$$

the third set is,

$$\Sigma\{\zeta(\alpha\beta\gamma\delta)\,.\left|\begin{array}{ccccccc}1, & [\epsilon], & [\epsilon\zeta], & ., & ., & ., & .\\ ., & 1, & [\epsilon], & [\epsilon\zeta], & ., & ., & .\\ ., & ., & 1, & [\epsilon], & [\epsilon\zeta], & ., & .\\ ., & ., & ., & 1, & [\epsilon], & [\epsilon\zeta] & \end{array}\right|\}=\begin{array}{r|cccccccc|} & + & - & + & - & + & - & + & -\\ -6 & b, & 5c, & 10d, & 10e, & 5f, & g, & ., & .\\ 1 & a, & 5b, & 10c, & 10d, & 5e, & f, & ., & .\\ 6 & ., & b, & 5c, & 10d, & 10e, & 5f, & g, & .\\ -1 & ., & a, & 5b, & 10c, & 10d, & 5e, & f, & .\\ -6 & ., & ., & b, & 5c, & 10d, & 10e, & 5f, & g\\ 6 & ., & ., & a, & 5b, & 10c, & 10d, & 5e, & f\end{array};$$

similarly for the fourth set; and the fifth set, which is the known value of $\zeta(\alpha\beta\gamma\delta\epsilon\zeta)$:—where such a symbol as $[\delta\epsilon]$ stands for $\delta\epsilon+\delta\zeta+\epsilon\zeta$, and [*] $\zeta(pqr)=(p-q)^2(p-r)^2(q-r)^2$.

APPLICATION TO STURM'S FUNCTIONS.

VII. The first set of equations for a sextic is

$$\Sigma\{(\alpha-\beta)^2\left|\begin{array}{cccccc}1, & [\gamma], & [\gamma\delta], & [\gamma\delta\epsilon], & [\gamma\delta\epsilon\zeta], & .\\ ., & 1, & [\gamma], & [\gamma\delta], & [\gamma\delta\epsilon], & [\gamma\delta\epsilon\zeta]\end{array}\right|\}=\left|\begin{array}{cccccc}P_1, & 2P_2, & 3P_3, & 4P_4, & 5P_5, & 6P_6\\ 6P_0, & 5P_1, & 4P_2, & 3P_3, & 2P_4, & P_5\end{array}\right| \quad (17).$$

For α, β, . . ., write respectively $x-\alpha$, $x-\beta$, . . . then we have

$$(\alpha-\beta)^2=(x-\alpha-x+\beta)^2=(\alpha-\beta)^2$$

and P_1 becomes

$$x-\alpha+x-\beta+x-\gamma+x-\delta+x-\epsilon+x-\zeta$$

$$=6x-P_1$$

$$\frac{6(ax+b)}{a}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (18),$$

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[*] This is the ζ-function of Professor SYLVESTER.

$$\begin{aligned} \mathrm{P}_2 \text{ becomes} \quad & (x-\alpha)(x-\beta)+(x-\alpha)(x-\gamma)+\ \ldots \text{ 15 terms} \\ = \ & 15x^2-5\mathrm{P}_1x+\mathrm{P}_2 \\ = \ & \frac{15(ax^2+2bx+c)}{a}\,; \qquad \ldots \ldots \qquad (19), \end{aligned}$$

$$\begin{aligned} \mathrm{P}_3 \text{ becomes} \quad & (x-\alpha)(x-\beta)(x-\gamma)+(x-\alpha)(x-\beta(x-\delta)+\ \ldots \text{ 20 terms} \\ = \ & 20x^3-10\mathrm{P}_1x^2+4\mathrm{P}_2x-\mathrm{P}_3 \\ = \ & \frac{20(ax^3+3bx^2+3cx+d}{a}\,: \qquad \ldots \ldots \qquad (20), \end{aligned}$$

so that, in general, we should find, instead of each P, all the terms of the sextic up to and including the term corresponding to the P in question, each term multiplied by the Binomial coefficient of its place in the expansion of the power the index of which is the same as the suffix of P; and the whole multiplied by the Binomial coefficient of the sixth power corresponding to the P considered, and divided by a.

The process is general, and, *mutatis mutandis*, is suitable for an equation of any degree.

Now, let such an expression as $ax^3+3bx^2+3cx+d$ be denoted by the symbol (d). Thus, the sextic in question would be $(g)=0$. Such a symbol implies Binomial coefficients. The *letter* will also, from its place in the alphabet, indicate the degree of the expression (or equation). This notation harmonises with that employed before, when x was zero.

Hence, writing (γ) for $x-\gamma+x-\delta+x-\epsilon+x-\zeta$, $(\gamma\delta)$ for $(x-\gamma)(x-\delta)+\ldots$, and so on,

$$a^2\Sigma\left\{(\alpha-\beta)^2\left|\begin{array}{cccccc} 1\,, & (\gamma)\,, & (\gamma\delta)\,, & (\gamma\delta\epsilon)\,, & (\gamma\delta\epsilon\zeta)\,, & . \\ .\,, & 1\,, & (\gamma)\,, & (\gamma\delta)\,, & (\gamma\delta\epsilon)\,, & (\gamma\delta\epsilon\zeta) \end{array}\right|\right\} = \begin{array}{c|cccccc|} & 1\,, & 5\,, & 10, & 10, & 5\,, & 1 \\ \hline 6 & (b), & (c), & (d), & (e), & (f), & (g) \\ 6 & (a), & (b), & (c), & (d), & (e), & (f) \end{array} \quad (21')$$

$$\text{or} \quad = \begin{array}{c|cccccc|} 6 & (b)\,, & 5(c)\,, & 10(d)\,, & 10(e)\,, & 5(f)\,, & (g) \\ 6 & (a)\,, & 5(b)\,, & 10(c)\,, & 10(d), & 5(e)\,, & (f) \end{array} \quad (21).$$

For example,

$$\begin{aligned} a^2\Sigma\{(\alpha-\beta)^2[&(x-\gamma)(x-\delta)+(x-\gamma)(x-\epsilon)+(x-\gamma),(x-\epsilon)+(x-\delta)(x-\epsilon)+ \\ &(x-\delta)(x-\zeta)+(x-\epsilon)(x-\zeta)]\}\,, \end{aligned}$$

$$= 360\left|\begin{array}{cc} (b)\,, & (e) \\ (a)\,, & (d) \end{array}\right|,$$

$$= 360\left|\begin{array}{cc} ax+b\,, & ax^4+4bx^3+6cx^2+4dx+e \\ a \quad , & ax^3+3bx^2+3cx+d \end{array}\right|.$$

Again,

$$a^2\Sigma\{(\alpha-\beta)^2(x-\gamma)(x-\delta)(x-\epsilon)(x-\zeta)\}=36\begin{vmatrix}(b)\,, & (g)\\ (a)\,, & (f)\end{vmatrix}$$

$$=\ 6^2a^2\times\text{the second of STURM's functions}\quad .\quad .\quad .\qquad(22);$$

the whole series of STURM's functions being $F'(x)$, $F_2(x)$, $F_3(x)$, ... where $6F'(x)$ is the first derived function of $F'(x)$, and the coefficient of the highest power of x in $F(x)$ is unity.

In like manner the second set of equations for a sextic gives rise to

$$a^4\Sigma\left\{\zeta(\alpha\beta\gamma).\begin{vmatrix}1\,, & (\delta)\,, & (\delta\epsilon)\,, & (\delta\epsilon\zeta)\,, & .\,, & .\\ .\,, & 1\,, & (\delta)\,, & (\delta\epsilon)\,, & (\delta\epsilon\zeta)\,, & .\\ .\,, & .\,, & 1\,, & (\delta)\,, & (\delta\epsilon)\,, & (\delta\epsilon\zeta)\end{vmatrix}\right\}=\begin{array}{r}6\\1\\6\\6\end{array}\begin{vmatrix}(b)\,, & 5(c)\,, & 10(d)\,, & 10(e)\,, & 5(f)\,, & (g)\,, & .\\ (a)\,, & 5(b)\,, & 10(c)\,, & 10(d)\,, & 5(e)\,, & (f)\,, & .\\ .\,, & (b)\,, & 5(c)\,, & 10(d)\,, & 10(e)\,, & 5(f)\,, & (g)\\ .\,, & (a)\,, & 5(b)\,, & 10(c)\,, & 10(d)\,, & 5(e)\,, & (f)\end{vmatrix}\quad(23).$$

Hence, for example,

$$a^4\Sigma\{\zeta(\alpha\beta\gamma).(x-\delta)(x-\epsilon)(x-\zeta)\}=6^3\begin{vmatrix}(b)\,, & 5(c)\,, & 10(d)\,, & .\\ (a)\,, & 5(b)\,, & 10(c)\,, & .\\ .\,, & (b)\,, & 5(c)\,, & (g)\\ .\,, & (a)\,, & 5(b)\,, & (f)\end{vmatrix}\qquad(24),$$

which may be written $\qquad =6^3\{\Delta'(f)-\Delta(g)\}$,

where

$$\Delta'=5(c).A-(b).B\quad\text{and}\quad A=\ 5\{(b)^2-(a)(c)\}$$

$$\Delta\ =5(b).A-(a).B\qquad\qquad B=10\{(b)(c)-(a)(d)\},$$

whence

$$(a)\Delta'=(b)\Delta-5^2\{(b)^2-(a)(c)\}^2.$$

Therefore we may write

$$a^4\Sigma\{.\ .\ .\ .\}=6^3\left[\frac{(b)(f)-(a)(g)}{a^2}\cdot a\Delta-5^2\{(b)^2-(a)(c)\}^2.\frac{(f)}{(a)}\right].$$

Also

$$(a)=a$$

$$(b)^2-(a)(c)=b^2-ac$$

$$(b)(c)-(a)(d)=2(b^2-ac)x+(bc-ad)$$

$$(b)(d)-(a)(e)=3(b^2-ac)x^2+3(bc-ad)x+(bd-ae)$$

$$(b)(e)-(a)(f)=4(b^2-ac)x^3+6(bc-ad)x^2+4(bd-ae)x+(be-af),$$

&c. &c.

Hence

$$\Delta=\begin{vmatrix}b\,, & 5c\\ a\,, & 5b\end{vmatrix}\left\{ax+5b-a\frac{10(bc-ad)}{5(b^2-ac)}\right\}\quad .\quad .\quad .\quad .\qquad(25),$$

and

$$a^4\Sigma\{\ \ldots\ \}=6^3\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}^2\left\{\mathrm{S}_2.a\frac{ax+5b-a\dfrac{10(bc-ad)}{5(b^2-ac)}}{\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}}-\mathrm{S}_1\right\}\quad . \quad (26),$$

where
$$\mathrm{S}_1=\frac{(f)}{a}=\text{STURM's first function},$$

$$\mathrm{S}_2=\frac{(b)(f)-(a)(g)}{a^2}=\text{STURM's second function},$$

that is,
$$a^4\Sigma\{\ \ldots\ \}=\frac{[\Sigma\{(a-\beta)^2\}]^2}{6}\times\text{STURM's third function}\quad . \quad (27).$$

It may be shown directly that $\dfrac{a\Delta}{\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}}$ is the proper multiplier of S_2 in finding S_3. For the sextic in question, STURM's second function is

$$\frac{(b)(f)-(a)(g)}{a^2}=\frac{5(b^2-ac)x^4+10(bc-ad)x^3+10(bd-ae)x^2+5(be-af)x+bf-ag}{a^2};$$

and if we assume $\mathrm{S}_3=\mathrm{Q}_2\mathrm{S}_2-\mathrm{S}_1$ where $\mathrm{Q}_2=px+q$, we find

$$\mathrm{Q}_2=\frac{a}{\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}}\left\{ax+5b-2a\frac{bc-ad}{b^2-ac}\right\},$$

which agrees with the former result.

Q_2 may be put in a more suggestive form, thus,

$$\mathrm{Q}_2=\frac{a}{\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}^2}\{5(ax+b).5(b^2-ac)-10a[2(b^2-ac)x+(bc-ad)]\}$$

$$=\frac{a}{\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}^2}\left\{5(b).\begin{vmatrix} (b)\,, & 5(c) \\ (a)\,, & 5(b) \end{vmatrix}-(a)\begin{vmatrix} (b)\,, & 10(d) \\ (a)\,, & 10(c) \end{vmatrix}\right\}$$

$$=\frac{a}{\begin{vmatrix} b\,, & 5c \\ a\,, & 5b \end{vmatrix}^2}\begin{vmatrix} (b)\,, & 5(c)\,, & 10(d) \\ (a)\,, & 5(b)\,, & 10(c) \\ \cdot\,, & (a)\,, & 5(b) \end{vmatrix}\quad .\ .\ .\ .\ .\ .\ .\ .\quad (28).$$

The third set of equations for a sextic is,

$$a^6.\begin{array}{c|c|r|cccccccc|}
\mathrm{S}' & \mathrm{P}' & & & & & & & & & \\
3 & 0 & =6 & (b)\,, & 5(c)\,, & 10(d)\,, & 10(e)\,, & 5(f)\,, & (g)\,, & \cdot\,, & \cdot \\
2 & 1 & 1 & (a)\,, & 5(b)\,, & 10(c)\,, & 10(d)\,, & 5(e)\,, & (f)\,, & \cdot\,, & \cdot \\
1 & 2 & 6 & \cdot\,, & (b)\,, & 5(c)\,, & 10(d)\,, & 10(e)\,, & 5(f)\,, & (g)\,, & \cdot \\
0 & 3 & 1 & \cdot\,, & (a)\,, & 5(b)\,, & 10(c)\,, & 10(d)\,, & 5(e)\,, & (f)\,, & \cdot \\
 & 4 & 6 & \cdot\,, & \cdot\,, & (b)\,, & 5(c)\,, & 10(d)\,, & 10(e)\,, & 5(f)\,, & (g) \\
 & 5 & 6 & \cdot\,, & \cdot\,, & (a)\,, & 5(b)\,, & 10(c)\,, & 10(d)\,, & 5(e)\,, & (f)
\end{array}\quad (29),$$

where the *dash* over S and P indicates that $x-\alpha$, $x-\beta$, ... have been substituted for $\alpha, \beta, \ldots\ldots$

Hence, after reductions similar to those of former cases,

$$\alpha^6\Sigma\{\zeta(\alpha\beta\gamma\delta).(x-\epsilon)(x-\zeta)\}=6^4\begin{vmatrix} (b), & 5(c), & 10(d), & 10(e), & 5(f), & . \\ (a), & 5(b), & 10(c), & 10(d), & 5(e), & . \\ ., & (b), & 5(c), & 10(d), & 10(e), & . \\ ., & (a), & 5(b), & 10(c), & 10(d), & . \\ ., & ., & (b), & 5(c), & 10(d), & (g) \\ ., & ., & (a), & 5(b), & 10(c), & (f) \end{vmatrix} \qquad (30).$$

Let us consider STURM's functions generally. We may write the following equations:—

$$\left.\begin{aligned} S_2&=Q_1S_1-S \\ S_3&=Q_2S_2-S_1 \\ S_4&=Q_3S_3-S_2 \quad \&c. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (31),$$

where each Q is of the first degree in x; and since S_{k-2} is two dimensions less than S_k, we can determine the coefficients in the value of Q. Let

$$\left.\begin{aligned} S_k&=s_k\,x^r+s'_kx^{r-1}+s''_k\,x^{r-2}+\ldots\ldots \\ S_{k-1}&=s_{k-1}x^{r+1}+s'_{k-1}x^r+s''_{k-1}x^{r-1}+\ldots\ldots \\ S_{k-2}&=s_{k-2}x^{r+2}+s'_{k-2}x^{r+1}+s''_{k-2}x^r+\ldots\ldots \end{aligned}\right\}; \quad . \quad . \quad (32),$$

on eliminating the coefficients in Q_{k-1}, after substituting in

$$S_k=Q_{k-1}S_{k-1}-S_{k-2} \quad . \quad . \quad . \quad . \quad (31'),$$

we have

$$s_k=-\frac{1}{s^2_{k-1}}\begin{vmatrix} s_{k-2}, & s'_{k-2}, & s''_{k-2} \\ s_{k-1}, & s'_{k-1}, & s''_{k-1} \\ ., & s_{k-1}, & s'_{k-1} \end{vmatrix}, \ s'_k=\&c., \&c. \quad . \quad . \quad (33),$$

and

$$Q_{k-1}=-\frac{1}{s^2_{k-1}}\begin{vmatrix} s_{k-2}, & s'_{k-2}, & . \\ s_{k-1}, & s'_{k-1}, & x \\ ., & s_{k-1}, & 1 \end{vmatrix} \quad . \quad . \quad . \quad . \quad . \quad (34).$$

For the purpose of reducing s_k, and presenting it as a function of $a, b, \ldots\ldots g$, it will be convenient to put

$$t_k=\begin{vmatrix} s_{k-1}, & s'_{k-1} \\ s_k, & s'_k \end{vmatrix}, \quad t'_k=\begin{vmatrix} s_{k-1}, & s''_{k-1} \\ s_k, & s''_k \end{vmatrix}, \ \&c. \quad . \quad . \quad (35),$$

whence,

$$s_k = -\frac{1}{s_{k-1}^2 s_{k-2}^4} \begin{vmatrix} s_{k-2}, & s'_{k-2}, & s''_{k-2} \\ \begin{vmatrix} t_{k-2}, & t'_{k-2} \\ s_{k-2}, & s'_{k-2} \end{vmatrix}, & \begin{vmatrix} t_{k-2}, & t''_{k-2} \\ s_{k-2}, & s''_{k-2} \end{vmatrix}, & \begin{vmatrix} t_{k-2}, & t'''_{k-2} \\ s_{k-2}, & s'''_{k-2} \end{vmatrix} \\ \cdot & , \begin{vmatrix} t_{k-2}, & s'_{k-2} \\ s_{k-2}, & s'_{k-2} \end{vmatrix}, & \begin{vmatrix} t_{k-2}, & t''_{k-2} \\ s_{k-2}, & s''_{k-2} \end{vmatrix} \end{vmatrix} = \frac{1}{s_{k-1}^2 s_{k-2}^3} \begin{vmatrix} t_{k-2}, & t'_{k-2}, & t''_{k-2}, & t'''_{k-2} \\ s_{k-2}, & s'_{k-2}, & s''_{k-2}, & s'''_{k-2} \\ \cdot & , t_{k-2}, & t'_{k-2}, & t''_{k-2} \\ \cdot & , s_{k-2}, & s'_{k-2}, & s''_{k-2} \end{vmatrix},$$

and, finally, on replacing the *t*'s by the *s*'s and reducing, we have

$$s_k = \frac{1}{s_{k-1}^2 s_{k-2}^2} \begin{vmatrix} s_{k-3}, & s'_{k-3}, & s''_{k-3}, & s'''_{k-3}, & s''''_{k-3} \\ s_{k-2}, & s'_{k-2}, & s''_{k-2}, & s'''_{k-3}, & s''''_{k-2} \\ , & s_{k-3}, & s'_{k-3}, & s''_{k-3}, & s'''_{k-3} \\ , & s_{k-2}, & s'_{k-2}, & s''_{k-2}, & s'''_{k-2} \\ , & , & s_{k-2}, & s'_{k-2}, & s''_{k-2} \end{vmatrix} \quad . \quad . \quad . \quad (36).$$

The process of reduction is general, and may be continued to any extent.

As an example, and to return to the third set of equations for the sextic.

$$s_4 = \frac{1}{a^8 \,.\, s_2^2 s_3^2} \begin{vmatrix} a, & 5b, & 10c, & 10d, & 5e \\ \begin{vmatrix} b, & 5c \\ a, & 5b \end{vmatrix}, & \begin{vmatrix} b, & 10d \\ a, & 10c \end{vmatrix}, & \begin{vmatrix} b, & 10e \\ a, & 10d \end{vmatrix}, & \begin{vmatrix} b, & 5f \\ a, & 5e \end{vmatrix}, & \begin{vmatrix} b, & g \\ a, & f \end{vmatrix} \\ \cdot, & a, & 5b, & 10c, & 10d \\ \cdot, & \begin{vmatrix} b, & 5c \\ a, & 5b \end{vmatrix}, & \begin{vmatrix} b, & 10d \\ a, & 10c \end{vmatrix}, & \begin{vmatrix} b, & 10e \\ a, & 10d \end{vmatrix}, & \begin{vmatrix} b, & 5f \\ a, & 5e \end{vmatrix} \\ \cdot, & \cdot, & \begin{vmatrix} b, & 5c \\ a, & 5b \end{vmatrix}, & \begin{vmatrix} b, & 10d \\ a, & 10c \end{vmatrix}, & \begin{vmatrix} b, & 10e \\ a, & 10d \end{vmatrix} \end{vmatrix},$$

which reduces to

$$s_4 = \frac{1}{a^6 \,.\, s_2^2 s_3^2} \begin{vmatrix} b, & 5c, & 10d, & 10e, & 5f, & g \\ a, & 5b, & 10c, & 10d, & 5e, & f \\ \cdot, & b, & 5c, & 10d, & 10e, & 5f \\ \cdot, & a, & 5b, & 10c, & 10d, & 5e \\ \cdot, & \cdot, & b, & 5c, & 10d, & 10e \\ \cdot, & \cdot, & a, & 5b, & 10c, & 10d \end{vmatrix} \quad . \quad . \quad (37).$$

VIII. The investigation shows that, for example, S_3 is proportional to

$$(1234)x^3 + (1235)x^2 + (1236)x + (1237) \quad . \quad . \quad (38),$$

where (1235) is the determinant formed from the 1st, 2d, 3d, and 5th columns of the matrix,

$$\left|\begin{array}{ccccccc} b, & 5c, & 10d, & 10e, & 5f, & g, & \cdot \\ a, & 5b, & 10c, & 10d, & 5e, & f, & \cdot \\ \cdot, & b, & 5c, & 10d, & 10e, & 5f, & g \\ \cdot, & a, & 5b, & 10c, & 10d, & 5e, & f \end{array}\right|$$

and in like manner for (1234), &c. :—the remaining factor in S_3, being independent of x. In other words, S_3 is proportional to the determinant,

$$\left|\begin{array}{ccccccc} \cdot, & \cdot, & \cdot, & \cdot, & \cdot, & 1, & -x \\ \cdot, & \cdot, & \cdot, & \cdot, & 1, & -x, & \cdot \\ \cdot, & \cdot, & \cdot, & 1, & -x, & \cdot, & \cdot \\ b, & 5c, & 10d, & 10e, & 5f, & g, & \cdot \\ a, & 5b, & 10c, & 10d, & 5e, & f, & \cdot \\ \cdot, & b, & 5c, & 10d, & 10e, & 5f, & g \\ \cdot, & a, & 5b, & 10c, & 10d, & 5e, & f \end{array}\right| \quad . \quad . \quad . \quad (39).$$

NOTE.—The signs of the constituents in the last four lines of the 2d, 4th, and 6th columns of this determinant are *minus* (see *e.g.*, (7) or (8); but attention has been paid to this in equations (40). This has been done for simplicity of writing.

This determinant is equal to another formed from it in the following manner:—Let C_7, *e.g.*, represent the 7th column; write

$$\left.\begin{array}{ll} \text{instead of } C_7, & C_1x^6 + C_2x^5 + C_3x^4 + C_4x^3 + C_5x^2 + C_6x + C_7 \\ \text{instead of } C_6, & 6C_1x^5 + 5C_2x^4 + 4C_3x^3 + 3C_4x^2 + 2C_5x + C_6 \\ \text{instead of } C_5, & 15C_1x^4 + 10C_2x^3 + 6C_3x^2 + 3C_4x + C_5 \\ \text{instead of } C_4, & 20C_1x^3 + 10C_2x^2 + 4C_3x + C_4 \\ \text{instead of } C_3, & 15C_1x^2 + 5C_2x + C_3 \\ \text{instead of } C_2, & 6C_1x + C_2 \end{array}\right\} \quad . \quad (40),$$

and leave the first column as it is.

This determinant will be found to reduce at once, to one of the fourth order, by the loss of its 1st, 2d, and 3d lines, and its 4th, 5th, and 6th columns; and thus S_3 is proportional to

$$\begin{vmatrix} b\ , & 6bx+5c\ , & 15bx^2+25cx+10d\ , & bx^6+5cx^5+10dx^4+10ex^3+5fx^2+gx \\ a\ , & 6ax+5b\ , & 15ax^2+25bx+10c\ , & ax^6+5bx^5+10cx^4+10dx^3+5ex^2+fx \\ .\ , & b\ , & 5bx+\ 5c\ , & bx^5+5cx^4+10dx^3+10ex^2+5fx+g \\ .\ , & a\ , & 5ax+\ 5b\ , & ax^5+5bx^4+10cx^3+10dx^2+5ex+f \end{vmatrix} \quad (41).$$

To reduce this, subtract the 3d line multiplied by x from the 1st; and the 4th line multiplied by x from the 2d; then, add the 2d line multiplied by x to the 1st; and the 4th line multiplied by x to the 3d; and finally, introducing the factors independent of x—

$$S_3 = \frac{1}{\begin{vmatrix} b\ , & 5c \\ a\ , & 5b \end{vmatrix}^2} \begin{vmatrix} (b)\ , & 5(c)\ , & 10(d)\ , & . \\ (a)\ , & 5(b)\ , & 10(c)\ , & . \\ .\ , & (b)\ , & 5(c)\ , & (g) \\ . & (a)\ , & 5(b)\ , & (f) \end{vmatrix} \quad . \quad . \quad . \quad (42),$$

which agrees with the result obtained before.

I shall write this last result in the form

$$S_3 = \frac{1}{\Delta_2^2} \cdot \Delta_4' \quad . \quad . \quad . \quad . \quad . \quad (43),$$

the Δ' always being function of x, and having all its last column zeros except the two lowest constituents, which are respectively (g), (f).

Let also those functions—called after their discoverer SYLVESTER, *Sylvester's functions*—be shortly expressed thus, *e.g.*,

$$\Sigma\{(\alpha-\beta)^2(\alpha-\gamma)^2(\beta-\gamma)^2(x-\delta)(x-\epsilon)(x-\zeta)\} \text{ by the symbol } \Sigma_3 \quad . \quad (44),$$

the suffix indicating the number of roots which enter into the squared product of differences under the Σ. Then the results arrived at may be collected in the form,

$$\left.\begin{aligned} \Sigma_2 &= 6^2\ \frac{\Delta_2'}{a^2} \\ \Sigma_3 &= 6^3\ \frac{\Delta_4'}{a^4} \\ \Sigma_4 &= 6^4\ \frac{\Delta_6'}{a^6} \\ \Sigma_5 &= 6^5\ \frac{\Delta_8'}{a^8} \end{aligned}\right\} \quad . \quad . \quad (45) \qquad \left.\begin{aligned} S_2 &= \frac{\Delta_2'}{a^2} \\ S_3 &= \frac{\Delta_4'}{\Delta_2^2} \\ S_4 &= \frac{\Delta_2^2 \cdot \Delta_6'}{a^2 \Delta_4^2} \\ S_5 &= \frac{\Delta_4^2 \cdot \Delta_8'}{\Delta_2^2 \quad \Delta_6^2} \end{aligned}\right\} \quad . \quad . \quad (46)$$

in which the law of succession is obvious. Hence

$$\left.\begin{aligned}
\Sigma_2 &= 6^2 . \mathrm{S}_2 & &= 6^2 . \mathrm{S}_2 \\
\Sigma_3 &= \frac{6^3 \Delta_2^2}{a^4} . \mathrm{S}_3 & &= \frac{1}{6} p_2^2 . \mathrm{S}_3 \\
\Sigma_4 &= \frac{6^4 \Delta_4^2}{a^4 \Delta_2^2} . \mathrm{S}_4 & &= 6^2 \frac{p_3^2}{p_2^2} \cdot \mathrm{S}_4 \\
\Sigma_5 &= \frac{6^5 \Delta_2^2 \Delta_6^2}{a^8 \Delta_4^2} . \mathrm{S}_5 & &= \frac{1}{6} \frac{p_2^2 p_4^2}{p_3^2} \cdot \mathrm{S}_5 \\
\Sigma_6 &= \frac{6^6 \Delta_4^2 \Delta_8^2}{a^8 \Delta_2^2 \Delta_6^2} . \mathrm{S}_6 & &= 6^2 \frac{p_3^2 p_5^2}{p_2^2 p_4^2} \cdot \mathrm{S}_6, \text{ \&c.}
\end{aligned}\right\} \quad . \qquad (47),$$

where $p_2 = \Sigma \{(\alpha-\beta)^2\}$, $p_3 = \Sigma \{(\alpha-\beta)^2 (\alpha-\gamma)^2 (\beta-\gamma)^2\}$; &c.

These results agree with SYLVESTER'S, and lead to the same conclusion, viz., that the number of imaginary roots depends on the number of variations of signs of the functions (*e.g.*, the sextic),

$$1 \; , \; 6 \; , \; \Delta_2 \; , \; \Delta_4 \; , \; \Delta_6 \; ; \; \Delta_8 \; , \; \Delta_{10} \; ,$$

and the values of these functions beginning with Δ_2 are respectively proportional to p_2, p_3, p_4, p_5, p_6.

The form Δ', (42), for successive STURM'S functions is interesting, and I believe new; as also the form (39).

XVI.—*On the Phenomena of Variegation and Cell-Multiplication in a Species of Enteromorpha.* By P. Geddes, F.R.S.E., Demonstrator of Vegetable Histology in the University of Edinburgh. (Plate XIII.)

(Received 4th April. Read 17th May 1880.)

In the autumn of 1877 I found on stones in a sea-water aquarium in Professor Huxley's laboratory at South Kensington, the curious little Alga which forms the subject of the present paper. I have ever since kept specimens growing, carried them with me to various places in Britain and on the Continent, and subjected them to frequent examination at all seasons of the year. Dr Bornet has kindly identified it for me as a species of *Enteromorpha.*

Viewed with a lens, the fronds are of a beautiful green, often more or less mottled with white. Examination of such specimens with a somewhat higher power (say 1 inch) shows among the ordinary green cells others which are smaller and colourless, occurring singly or in patches of very variable size. Oftener than these variegations of the frond itself, one notices buds, or even large branches, which are completely colourless. And the extreme case—of large fronds, and indeed whole tufts, almost without any green cells, is not wanting. How are these phenomena to be accounted for ?

The first hypothesis which suggests itself is that here we have an etiolation of green cells,—a mere blanching of particular cells or fronds, due to the interception of the light by the felt-work of *Oscillatoriæ, Confervæ,* &c., by which the specimens were always more or less thickly surrounded. But it will be seen from an inspection of the plate that the colourless cells are oftenest apical; and when a fragment of the very thickest part of this vegetable felt is detached and viewed under the simple microscope, colourless shoots are to be seen projecting clear above the tangled mass of other Algæ, while the portion of the frond thus shaded may be of the deepest green. Moreover, specimens kept growing for months in a window, exposed to direct sunlight for several hours daily, never lost their variegated aspect. A crucial experiment enabled me finally to exclude the hypothesis of a mere etiolation of normally green cells by deficiency of light. A flint covered with an abundant crop of the Alga under examination was broken into three pieces, of which one was exposed to sunshine for six or seven hours a day, another kept in the diffuse light of my workroom, and another placed in darkness. After the lapse of three or four weeks no change was appreciable. On the stone exposed to direct sunlight there seemed to be as many colourless cells as ever, though it is well known that a few hours in such conditions suffice to develop chlorophyll in blanched vegetable cells. Nor did those kept in darkness show any distinct increase in the proportion of white cells to green. In fact, when the three pieces of flint were again placed together in the same aquarium, an attempt to identify them again by examination of the Algæ they bore, failed completely.

I do not deny, however, the importance of the action of light, for I have found white buds more abundantly in winter than in summer; but it is evident that such an experiment as the foregoing, twice repeated, excludes the hypothesis of etiolation. Moreover, the long period over which my observations have extended, the many changes of climate and of circumstances to which the plants have been exposed, and above all, the fact that the white shoots were more abundant the more active and more vigorous the growth, are all arguments in favour of the normality of this mode of vegetation. I should, however, consider it premature to assign any specific or generic name before examining more specimens from other sources; and it may not improbably turn out that these phenomena of variegation may occur as a kind of *sport* in many species of Algæ.

The colourless buds, then, demand a closer examination. At one side of the frond or filament, and generally midway between two green cells, is often to be seen a slight prominence of cellulose enclosing a tiny droplet of colourless non-nucleated hyaline protoplasm (figs. 1*a*, 11). A farther stage is represented in fig. 12, where there are two similar but larger masses, and a farther still in fig. 13, where there are three; in short, all stages are to be found up to a comparatively long row of colourless nucleated cells, such as that represented in fig. 14 or 23. The existence of a series of perfect gradations between a single minute non-nucleated droplet of clear protoplasm, and a distinct row of nucleated and granular cells, shows that the colourless shoot arises in a way totally distinct from that by which the ordinary green cells are developed.

Such transparent cells multiply by transverse division, and have also the power of developing chlorophyll. While the majority of the colourless shoots are sharply marked off by their colour and general appearance from the green part of the frond (figs. 13, 14), others are to be found in which there is a gentle gradation from white cells to green (figs. 1*b*, 15, 24, 28), the development of chlorophyll beginning at the base of the shoot, and proceeding upwards.

Cases in which the colourless cells are irregularly interpolated among the green, as has been already said, are not uncommon. Sometimes one finds the cells of a green filament separated by the development of one or several colourless cells (figs. 16, 19, 26); sometimes these may multiply greatly, so as to push the original green portions of the frond far apart from each other, and so produce such extraordinary forms as those represented in figs. 18 and 19, where green shoots are seen as if arising from a colourless frond.

The co-existence of two distinct kinds of cell being admitted, it is desirable next to ascertain the process by which these arise. With the green cells there is no difficulty; their multiplication by transverse division is obvious; but it is by no means easy, without the examination of a vast number of specimens, to satisfy oneself as to the mode of origin of the colourless cells, or rather of that droplet of hyaline protoplasm (fig. 11) from which the colourless cell originates.

The cellulose of an Alga is, as has been known from the time of Kützing and Rabenhorst, no mere structureless investment, but possesses a *capsular* structure, quite similar to that which is so easily seen in *Glœocapsa,* or to that which has been demonstrated in the matrix of hyaline cartilage. This structure is shown in figs. 2 and 3, particularly well in the latter. Its origin is obvious; a cell throws out a coat or shell of cellulose, and then divides into two new cells; each develops its own investment of cellulose, and these lie end to end within the first. The extremities of these new cells being biconvex, they are thus not in complete apposition, but an angular interspace is left, which extends ring-fashion round the filament. Any irregularity of form or growth in the cell produces a corresponding irregularity in the disposition of the cellulose, and thus too in the form of the intercellular space, perhaps suppressing it on one side and enlarging it at the other.

It is not to be expected that these laminæ of cellulose should be of precisely equal thickness and strength throughout, nor of equal permeability to fluids. Where a weak place in the cellulose wall happens to come opposite the intercellular space, a certain amount of water might easily enter the latter from the cell; this water might soften and swell the circumjacent cellulose, and thus protuberances of the cellulose, and of the cellulose alone, such as those represented at figs. 5, 6, 7, 9, and 10, would easily arise. These phenomena are most probably to be considered as pathological.

But if instead of a mere exosmose of water through the wall, we suppose the growing protoplasm itself to force a passage through the least resisting point in the innermost capsule of cellulose into the intercellular space, we have at once a reasonable explanation of the origin of the tiny drops of colourless protoplasm already described (fig. 11). Their position, almost invariably evenly intercalated between two given cells (fig. 7*a*), or at one side of the plane separating them (fig. 11); and their forms, biconcave and lenticular in the first case, hemispherical in the second, are strong proofs of their origin in this way.

The cells at the bottom of the white shoots in figs. 2, 22, 23, 26, &c., are obviously each in an intercapsular space, and their protoplasm (which has in some cases developed a nucleus, in others none) sometimes even half surrounds the innermost cellulose capsule of the adjacent green cell, and looks almost as if it were going to enclose it altogether. Such buds as these we have been imagining, arising as they would from the colourless ectoplasm of the green cell, would necessarily be themselves colourless. And instances are not wanting in vegetable and even in animal histology of the independent development of a nucleus and nucleolus within a cell.

It is possible to verify this hypothesis of the origin of the white cells by direct observation. Generally the colourless cells seem totally distinct and separate from the coloured (figs. 1, 2, 4*a*, &c.), but occasionally one can see with the utmost clearness (figs. 4*b*, 19, 27) the process of formation of the colourless cells by the intrusion of the colourless ectoplasm of the green cell into an intercellular space. In fig. 20 are to be seen pseudopodium-like processes of colourless protoplasm pressing into soft swellings of the cellulose. At figures 19 and 27, the intercellular space is being filled up by a flow of such protoplasm from the green cell; while in fig. 4*b* the formation of a lateral bud is going on.

In this Alga, then, we have simultaneously in progress two distinct modes of cell-formation; first, the ordinary process of vegetative growth by transverse fission; secondly, a process of gemmation tolerably similar to that which takes place in *Torula*. The cells produced by this second process are often to be seen dividing transversely (fig. 31), and it is not impossible that they may also give rise to new colourless cells by the same process as that by which they themselves were produced (figs. 19, 28).

The Alga in question is also of some interest from the physiological point of view. It would be interesting to ascertain how plants so nearly destitute of chlorophyll as that represented in the last figure, which possesses only two cells capable of decomposing carbonic acid, can possibly live and grow.

EXPLANATION OF THE PLATE.

(*Figures mostly drawn with Hartnack,* Oc. 3, Obj. 7 *or* 9.)

Fig. 1. Young growing fronds, showing (*a*) colourless buds of various sizes; (*b*) an originally colourless shoot of which the cells have almost all developed chlorophyll.

Fig. 2. A frond bearing a terminal colourless shoot, and showing indistinctly the capsular arrangement of the cellulose.

Fig. 3. Young frond treated with weak potash solution, showing very distinctly the capsular arrangement of the cellulose.

Fig. 4. Frond showing (*a*) young colourless cell devoid of nucleus; (*b*) another budding off from green cell.

Figs. 5, 6, 7, 8, 9, 10. Fronds showing outgrowths and thickenings of the cellulose alone.

Figs. 11, 12, 13, 14. Showing colourless shoots of various sizes.

Fig. 15. Colourless shoot acquiring chlorophyll.

Fig. 16. Frond in which colourless cells are irregularly developed among green cells.

Figs. 17, 18. Fronds in which such irregularly interposed colourless cells have greatly multiplied, so as to push the original green parts of the frond far asunder, and to produce the appearance of green shoots arising from a white frond.

Fig. 19. Gemmation of colourless cells from green very clearly shown.

Fig. 20. Shoot in which green cells are sending out colourless processes, probably incipient buds.

Figs. 21, 22, 23. Apical colourless shoots of various sizes.

Fig. 24. Shoot similar to fig. 23, developing chlorophyll.

Fig. 25. Tip of frond of which the two terminal green cells have been carried up by the development of a colourless shoot below them.

Fig. 26. Frond with apical white shoot.

Fig. 27. Mode of origin of colourless from coloured cells very clearly shown (see figs. 4 and 19).

Fig. 28. Colourless shoot developing chlorophyll, bearing already a lateral colourless bud.

Fig. 29. Similar lateral colourless bud farther advanced.

Fig. 30. Showing probable mode of formation of such lateral colourless buds by displacement of a cell.

Fig. 31. Tip of colourless shoot showing its cells in process of division.

Fig. 32. Frond entirely destitute of chlorophyll save two basal cells.

XVII.—*On the Disruptive Discharge of Electricity.* Part IV. (Plate XIV.)

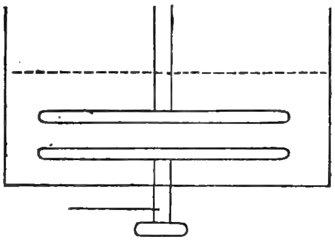
By A. MACFARLANE, M.A., D.Sc., F.R.S.E., and P. M. PLAYFAIR, M.A.

(Read 6th January 1879 and 19th July 1880).

The following experiments, in continuation of our research on the discharge of electricity, were made in Professor TAIT's Laboratory during the College Session 1878–79, and papers briefly describing the results were read before the Society on 6th January 1879 and 19th July 1880.

Discharge of Electricity through a Paraffin in different States.

By favour of Mr CALDERWOOD, Manager of Addiewell Chemical Works, we obtained a quantity of a pure paraffin of low melting point. We have recorded in Table I. a series of observations which we made to compare its electric strength when solid and when liquid with that of air at the atmospheric pressure. By the electric strength of a dielectric we mean the ratio of the electromotive force required to pass a discharge through the dielectric to that required for air under the same conditions, and when the length of spark is 5 mm. It is necessary to make the comparison at a fixed length of spark, as in the case of the gases the electromotive force is not proportional to the length of the spark. In the case of some liquids, we found that we could not take measurements for a 5 mm. spark; in such cases we make the comparison at the greatest length of spark for which observations have been taken.



A cylindrical glass dish 7 inches in diameter, had a brass screw passed through the centre of the bottom, to which one of the 4-inch circular plates could be screwed on, as represented in the woodcut. The lower plate was connected with the earth by attaching a wire to the outside part of the brass screw. The upper plate was suspended from the rod of an air-pump receiver so as to be parallel to the lower plate, and at a distance of 3 mm. A sufficient quantity of the liquefied paraffin was poured in to fill the dish to the height indicated in the woodcut, and it was allowed to solidify for twenty-four hours. We were particularly careful to note properly the reading for the first spark, as we knew that we could not get a second of the same kind without melting the paraffin again. It will be observed from the table that the deflections for the succeeding four sparks are sensibly equal. The ratio of the electromotive force for the first discharge to that for the succeeding discharges is 3·6. The increased facility is of course due to the fact that the first discharge bores a hole through the solid. We observed the hole afterwards; it was zigzag as regards direction, and had a black surface. The passage of the sparks, and particularly of the first one, illuminated the whole cake of paraffin in a very beautiful manner.

The paraffin was then taken out, and sparks taken for air under the same conditions as before. The mean reading for air compared with the reading for the solid paraffin gives the electric strength of the former to be five times that of the latter.

Next we liquefied the paraffin and raised it to a pretty high temperature, so that it might remain liquid for some time though brought into contact with the cold dish and plates, and then poured it in to the same height as before. The mean reading gives its electric strength when liquid to be 2·4—scarce half of that which it possesses when in the solid state. The further observations were taken to see how rapidly the electric strength changed. The deflection when the paraffin was quite clear was 230; this increased for the next three observations up to 390, when the paraffin was superficially solid; but the effect of this spark was to make a rent which allowed the discharge to pass more easily afterwards. These results are supported by other two sets of observations, which were preliminary in their nature.

Discharge of Electricity through Olive Oil.

We thought it of importance to ascertain whether that law of discharge holds for olive oil which we had already found to hold for the two dielectrics, paraffin oil and oil of turpentine, viz., that the electromotive force plus a constant is proportional to the distance between the parallel plates forming the electrodes. (Trans. Roy. Soc. Edin., vol. xxviii. p. 680). With that view, and also for the purpose of comparing its electric strength with that of air, we took the series of observations recorded in Table II. We found it possible to continue the observations for a distance greater by one millimetre than in the case of the other two liquids. When the distance was increased to 6 mm. the index moved up pretty steadily to 0 divisions of the scale, when it suddenly left the scale on account of the great amount of electricity which then began to escape from the insulated wire. In the fourth column we have noted the position which the index took up after the passage of the spark and the discharge of the conductors of the Holtz machine, but the deflection to the negative side of the original zero (530) was so considerable that we always brought the index back to 530 before taking another reading, by touching the ball of the electrometer with the hand. We have plotted the results in the diagram, Plate XIV. The crosses mark the difference given in the fifth column, and the dots with circles mark the differences given by subtracting the deflections from the original zero, 530. The first of these is probably the proper curve, but whichever of the two we take, we get a straight line having a small negative intercept on the axis of ordinates precisely as in the case of the other two liquids. The curve, instead of showing a tendency to become concave to the axis of abscissæ, exhibits a tendency to become convex with respect to it, thus differing in a remarkable manner from the curve obtained for a gas. The equations to the two curves within the limits of observation are,

$$V = 900\, s - 30 = 298\, s - 10 \text{ in C. G. S. units, and}$$
$$V = 760\, s - 17 = 252\, s - 6 \text{ in C. G. S. units,}$$

where V denotes the difference of potential, and s the length of the spark in centimetres.

The reading for a 5 mm. spark in air under the same conditions, given as a mean by four observations, was 119; hence the electric strength of olive oil is 3·5. This is less than that for paraffin oil or oil of turpentine (4 and 3·7 respectively), as we expected from the fact that we were able to continue the observations through a slightly greater range of length of spark.

The difficulty of making these observations was very considerable, as the oil had to be freed and kept free of all solid particles (Trans. Roy. Soc. Edin., vol. xxviii. p. 673), and the passage of a spark also produced bubbles of gas which had to be removed from between the plates before another reading could be taken. In the case of each of the three liquids we have examined, the discharge has been accompanied with decomposition of the substance. Having finished the readings, we took a note of the behaviour of these bubbles. When the plates were 11 mm. apart and the upper one charged positively, the bubbles were repelled downwards, and when suspended in the liquid, assumed the form of prolate spheroids, with the long axis in the direction of the lines of force. They discharged the electricity by convection. When the upper plate was negative the bubbles appeared to be repelled less strongly. The spark when examined by the spectroscope showed red and green with a tinge of violet.

With the view of ascertaining the effect of condensed gas on the passage of the spark, we substituted palladium wires for the platinum wires in the instrument described in Trans. Roy. Soc. Edin., vol xxviii. p. 682. We charged these palladium electrodes with hydrogen in the usual manner, took a number of sparks between them, then having heated the wires by means of a battery of four Bunsen elements, we took sparks again. Our observations do not indicate decisively any results, but they point out conclusions which may be established by further experiments.

TABLE I.—*Discharge of Electricity through Paraffin.—5th December* 1878.

Electrodes, Parallel Plates each four inches in diameter. Length of Spark, ·3 centimetre.
Jars on Holtz Machine.

Dielectric.	State of Dielectric.	Deflection, n.	Zero, n'.	Difference of Potentials, $n'-n$.		Diff. of Potentials in C. G. S. Units.	Electric Strength.
Paraffin in Solid State.	1st Spark,	40	510	470		130	5·0
	2d ,,	380	...	130	130		
	3d ,,	385	...	125			
	4th ,,	380	...	130			
	5th ,,	370	...	140			
	After interval of 10 minutes,	370	...	140			
Air.	...	416	508	92	95	26	1·0
		417	...	91			
		408	...	100			
		410	...	98			
Paraffin in Liquid State.	Quite clear,	260	505	245	230	62	2·4
		270	...	235			
		290	510	220			
		288	...	222			
	Beginning to solidify on plates, . .	275	520	245			
	Solidified on sides of glass vessel, . .	200	520	320			
	Surface of paraffin solidified,	130*	520	390			
	After some time,	200	515	315			
	After some time,	250	510	260			

* Surface blown up by discharge.

TABLE II.—*Discharge of Electricity through Olive Oil.*—*29th May* 1879.

Electrodes, Parallel Brass Plates, each four inches in diameter. No Jars on the Holtz Machine.

Dielectric.	Length of Spark, *s*.	Deflection, *n*.	Zero, *n′*.	Observed Difference of Potentials, *n′–n*.	Mean Difference of Potentials.	Mean Difference of Potentials in C. G. S. Units.	Electric Strength.
Air,	·5	410	525	115			1·0
		415	...	110	119	39·7	
		390	...	135			
		410	...	115			
Olive Oil,	·1	470	528	58	61·5	20·4	3·5
		465	530	65			
	·2	405	550	145	150	49·6	
		395	...	155			
	·3	335	...	215	237·5	78·4	
		310	570	260			
	·4	250	600	350	330	109	
		250*	560	310			
	·5	150	...	410	420	139	
		180	610	430			
	·6	about 0					

* Electricity escaped from the insulated wire before the discharge took place.

XVIII.—*Researches in Thermometry.* By EDMUND J. MILLS, D.Sc., F.R.S. Communicated by Professor Sir WILLIAM THOMSON, D.C.L., F.R.S.

(Read May 3, 1880.)

In the course of a series of experiments upon fusion point, as determined by the mercurial thermometer, I had occasion to investigate several of the properties of that instrument. In the hope that the results of that investigation may economise the labour of other experimenters, and aid in its accuracy, I have ventured to submit them to the consideration of the Society. The memoir comprises the following sections :—

I. Calibration and the calibration unit.
II. The exposure correction.
III. The movement of the zero with (α) time, and (β) temperature.
IV. POGGENDORFF'S correction.
V. Comparison of the mercurial with the air thermometer.
VI. Effect of compression.

I. CALIBRATION AND THE CALIBRATION UNIT.

Various methods have been proposed for calibrating finished thermometers, all agreeing in using a small thread of mercury, say twenty scale divisions long, or less, as a calibration unit. I find it a much easier plan to calibrate the graduated stem before the bulb is blown on. For this purpose the stem is placed in a horizontal position, parallel to a horizontal kathetometer. By means of a piece of india-rubber tubing attached to one of its ends, a thread of mercury of suitable length can be drawn in at the other end; this also is then furnished with a similar piece of tubing. By means of these pieces of tubing the mercurial thread can be placed in any desired position.

According to the ordinary method, one extremity of the thread (say the left) is brought to the zero of the scale, and the position of its other extremity ascertained. By carefully shifting the thread the left extremity is brought exactly to the point where the right previously stood, and a new reading is made; similar determinations are made all along the scale. This process is tedious in the extreme, on account of the great precision required at each placing of the thread. The following method,* which is equally accurate,

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* Since writing the above I have found evidence that this method was used by BESSEL for ascertaining positions (*Pogg. Ann.* lxxxii. p. 290).

depends upon adjusting the thread so as to have only a slight error, and then immediately correcting for this error. It is carried out as illustrated in the accompanying section of a thermometer. Suppose the first position of the thread to have been, as shown, 0—26·9 on the scale. By sucking a little air from the right hand india-rubber tube, or by blowing a little air into the left hand tube, the thread is now caused to occupy, say 29·6—54·9 on the scale; that is, it has been placed 2·7 divisions too much to the right. The corrected position is therefore 26·9—52·2; and the lengths corresponding to the two positions are 26·9 and 25·3 successively. In practice the misplacement never need exceed ·2 or ·3 millimetre, a quantity that can be subtracted without introducing any sensible inaccuracy. It is advisable, in order to neutralise constant error, to make one entire calibration to the right, and one to the left; the mean of these should be adopted.

Fig. 1.

The degree value of the calibration unit is, of course, ascertained by determining how many times it is contained in a scale whose extreme points are the melting-point of ice and the boiling-point of water. LAPLACE's standard atmospheric pressure* for 100° C. is

$$\{760+\cdot 0001492H+1\cdot 946\cos 2\lambda\}\text{ millimetres};$$

H being the height in metres above sea-level, and λ the latitude. In my own experiments, which were performed in London, the temperature corresponding to 760 millimetres was found, by the aid of this expression, to be 100°·012.

On account of the secular diminution in the capacity of the bulb (which diminution is much greater at zero than at 100°) the value of the calibration unit may undergo a measurable diminution. The following is a comparison of five values of x, taken at a considerable interval of time apart, in the expression

$$\text{New unit}=x\text{ old unit.}$$

Thermometer.	2	3	6	454	C.
x.	·99945	·99789	1·00013	·99986	·99997.

Thus in all the above cases, excepting one, there has been a diminution in the value of the unit; but the increase for thermometer 6 lies well within a fair allowance for experimental error.†

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* MILLER, *Phil. Trans.* (1856), p. 775.

† A series of measurements of changes in the scale value of the 0° – 100° interval was made by PIERRE, *Ann. Ch. Phys.*, 1842 (444).

It is clear that, for all accurate work, the degree value of the calibration unit should from time to time be re-determined. Where this cannot be done, as for instance in geographical expeditions (in which thermometers are used to determine heights, by boiling-point observations), the results are to a certain extent untrustworthy.

II. The Exposure Correction.

If the indicating portion of a thermometer be only partially immersed in a medium whose temperature it is intended to exhibit, there will be a ± correction, according as the temperature of the air is below or above that of the medium. This is generally determined by placing the bulb of a subordinate thermometer half way up the exposed or free portion of the indicating column, and then calculating out the value of y in

$$y = \cdot0001545(\mathrm{T} - t)\mathrm{N}.$$

In this expression y is the correction; ·0001545 is the difference between the coefficients of cubical expansion of mercury and glass; T, t are the readings of the principal and subordinate thermometers in centigrade degrees; and N is the total number of scale degrees exposed.* Regnault, who devised this formula, did not verify it by experiment. I have therefore instituted a series of trials in which the numerical coefficient above specified is regarded as a quantity x to be determined.

The method of operation consisted essentially in placing a long and delicate thermometer vertically in a current of steam, the thermometer being held in the same position throughout, but varying in the depth of its immersion in the medium. The apparatus, of which a drawing is given below, consists of a thin glass flask holding at a about 1·4 litres of boiling water, to which a trace of zinc dust is added. From this proceeds a piece of hard glass tubing, 1·4 centimetres in diameter, encased in thick india-rubber tubing. Through the top of the glass tube passes the long

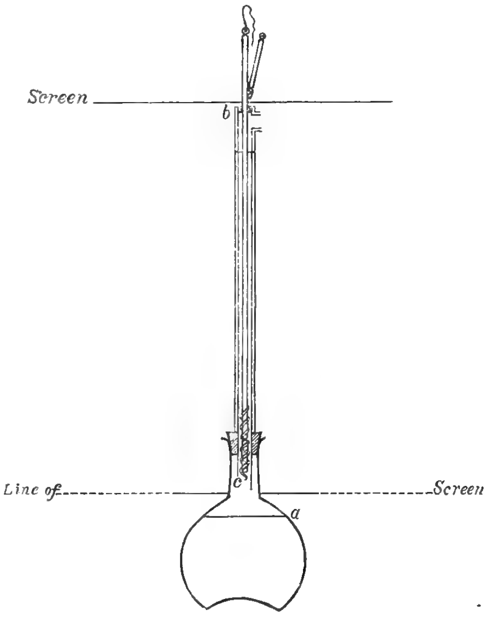

Fig. 2.

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* *Mémoires de l'Acad.* xxi. p. 225.

thermometer submitted to experiment; it is held suspended vertically by a wire, and prevented from touching the sides of the tube by a collar of cork at *b* and an open lead helix at *c*. The upper part of the glass tube consists of a T-piece, whose lateral portion serves to carry off steam. By taking glass tubes of different lengths it is thus easy to obtain data for calculating the unknown coefficient x. One precaution, however, is necessary to be carefully borne in mind. The level of the liquid in the flask must not be allowed to vary much, or to descend below the mark *a*; otherwise heated air from the gas flame below is sure to lap round and overheat the emerging steam, thereby rendering all the readings useless. In order to entirely remove any source of error from overlap, a screen of tinned sheet-iron 61 centimetres square was perforated and dropped over the flask nearly as far as *a*; the subordinate thermometer was also screened. In spite of every precaution, there appears to be in the experiments some source of variation which I could not detect; and as the value of x is very small, it became necessary to take very numerous readings before constant means could be obtained for it.

Table I. contains the numerical results furnished by thermometer 2. The unit length of N is a millimetre (valued at about 0°·25 C.). The lengths given as read are each the mean of fifteen readings, and the table involves altogether 2160 readings.

TABLE I.

N.	x.	N.	x.	N.	x.
393·95 to 310	·00015373	392·90 to 210	·00014414	391·85 to 110	·00014435
393·50 „ 310	·00011323	392·22 „ 210	·00014377	391·00 „ 110	·00014966
391·04 „ 290	·00013067	390·00 „ 190	·00013679	388·90 „ 90	·00014065
390·00 „ 290	·00013618	388·95 „ 190	·00013605	397·91 „ 90	·00014021
392·11 „ 290	·00014551	390·97 „ 190	·00014659	389·86 „ 90	·00014777
395·02 „ 290	·00014724	393·76 „ 185	·00015171	392·50 „ 90	·00015749
394·25 „ 295	·00015180	393·10 „ 210	·00016206	391·90 „ 105	·00015655
393·25 „ 307	·00015901	392·02 „ 210	·00014487	390·90 „ 100	·00014095
391·30 „ 250	·00015257	390·27 „ 155	·00014905	389·27 „ 85	·00016062
391·90 „ 280	·00013677	390·57 „ 180	·00015584	389·27 „ 80	·00016598
392·45 „ 280	·00015670	391·28 „ 180	·00015720	390·19 „ 80	·00015720
395·00 „ 280	·00013999	397·75 „ 180	·00014817	392·70 „ 85	·00015055
395·19 „ 280	·00016433	394·00 „ 180	·00015861	392·90 „ 80	·00015686
395·40 „ 280	·00015737	394·10 „ 180	·00016332	393·00 „ 80	·00016013
395·75 „ 290	·00014182	394·29 „ 190	·00016504	393·07 „ 90	·00016598
395·00 „ 290	·00013284	393·85 „ 190	·00013909	392·75 „ 90	·00614327
Means— 393·44 to 288·25	·00014498	392·25 „ 189·37	·00015014	391·75 „ 90·94	·00015239

From the means of all the results we obtain the equation :

$$x = \cdot 00014148 + \cdot 000000037880\text{N} .$$

In other terms, for equal increments of exposure, x receives equal increments in value. The comparison is—

N.	x Found.	x Calc.	Diff.
105·19	·00014498	·00014546	+ ·00000048
202·28	15014	14917	− 97
300·81	15239	15284	+ 45

The probable error of a single determination of the middle tabular coefficient ·00015014 is ·0000063155, or 4·21 per cent. ; of the mean of the sixteen determinations, ·0000015790, or 1·05 per cent.

Similar experiments, of about the same value, have been made with other similar thermometers. The resulting equations are :

Therm.	Equation.
3	$x = \cdot 00013197 + \cdot 000000057030\text{N}$,
4	$x = \cdot 00012513 + \cdot 000000058727\text{N}$,
6	$x = \cdot 00013427 + \cdot 000000058547\text{N}$.

The values of y agree first when N has the following values :—

Therm.	N.
2	0·0 ,
3	166·0 ,
4	278·6 ,
6	123·2 .

Thus each thermometer is proved to have its own independent equation for exposure correction ; and the general equation to y, the correction is—

$$y = (\alpha + \beta\text{N})(\text{T} - t)\text{N} .$$

For all ordinary purposes, and certainly for short exposures, we may take the mean of the above four equations ; and thence, in terms of the centigrade scale,

$$y = (\cdot 00013321 + \cdot 000000013261\text{N})(\text{T} - t)\text{N} .$$

Thus, if we suppose $(\text{T} - t)$ to remain constant, the correction is proportional to the square of the length of scale exposed ; and the relation between them is graphically represented by a parabolic curve.

That the coefficient $\alpha = \cdot 0001545$ is too large in a particular case was noticed by the author of the article "Schmelzpunkt" in the *Handwürterbuch der Chemie,* vii. 368; and he suggested that ·000135 would be more accurate generally. This number does not differ much from one deducible for short exposures from my own formula.

According to MOUSSON'S hypothesis,* the exposed capillary column of mercury is, together with the glass tube containing it, in the same predicament as a rod conducting heat applied at one of its extremities. He determines the correction as follows:—The thermometer is completely immersed in a large bath whose temperature changes very slowly, and a reading taken; it is then, after an interval of say five minutes, raised N^0 out of the bath; and these operations are repeated. The mean of the first readings gives the actual temperature T of the liquid; the mean of the second readings furnishes a lower number T′. The difference $\Delta T' = T - T'$ is thus known, and yields the constant

$$\epsilon = \alpha N - \frac{\Delta T'}{T'} ,$$

which implies the hypothesis in question. If in any given case a correction $\Delta T'$ has to be made when T′ and N are observed, we have

$$\Delta T' = T'(\alpha N - \epsilon) ,$$

an equation from which, by two observations, α could be calculated if required.

WULLNER† gave in the same year a very similar formula; adding, however, an observation of the temperature of the top of the column. Neither of these expressions has hitherto been submitted to any extended experimental verification.

It is plain that various expressions may equally well represent small total corrections. In this case it seems inaccurate to assume that a vertical thermometer, consisting of two materials heated below, and therefore causing an upward current of diminishingly warm air at the outer glass surface, is merely in the condition of a uniform rod heated at one end, and conducting heat in a medium at uniform temperature and free from convection. The experimental state of affairs is probably this. With an exposure of medium or considerable length, the current of heated air at the thermometer's surface heats the instrument much faster, and higher up, than it could be heated by conduction; the temperature of the middle of the exposed part must therefore be a close approximation to the mean temperature required. In the case of a short exposed length, conduction may play a more important part then con-

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* *Pogg. Ann.* cxxxiii. (1868) p. 316.

† *Lehrbuch der Experimentalphysik,* iii. pp. 295–298.

vection, and the middle temperature is not improbably too low; yet the error will now have but little effect, because the correction for short lengths is comparatively small.

A complete investigation of the exposure correction would require to take into account (1) the law of conduction of a mercury-glass rod, (2) the law of thermal access by convection of more or less heated air at the rod's surface, and (3) the law of relation between temperature and the difference between the volume expansions of mercury and glass. Lastly, there is the practical difficulty of ascertaining the temperature of a mercury-glass rod by means of an ancillary instrument placed at its edge, and the circumstance that unannealed glass is not likely to be isotropic. It is clear from MOUSSON's investigation that, taking conduction into account, we diminish the correction; upward convection of warm air must act in the same way; and it appears very probable that the difference between the coefficients of expansion of mercury and glass increases as the temperature (or exposure) increases. These effects are embodied in the formula which, taking REGNAULT's as a basis, I have deduced from very numerous experiments, and which therefore includes the convection effect.

III. ZERO MOVEMENTS.

The movements in the zero of a thermometer, when the pressure upon it is constant, are due primarily to a difference of temperature between some given initial state and some state brought about thereafter.

The bulb of a thermometer consists of glass, that is, of a mixture in various proportions of more fusible, less crystalline, basic silicates with less fusible, more crystalline acid silicates. During the operations of blowing it becomes richer in silica, and hence of a more crystalline nature. The crystalline portion, in all probability, takes many years to complete its separation—however rapid at first—from the amorphous constituents; and this separation should be attended with some slight contraction of volume. The mixture is also especially sensitive to the influence of temperature, more particularly soon after its manufacture; and thus it exhibits—after heating, for example—a "set," the recovery from which is comparatively slow.

Movements in the zero of a thermometer may be investigated in two ways, according as we make (1) time or (2) an immediate temperature disturbance the leading feature of our study.

Movement of the Zero with Time.

The ascent of the zero of a thermometer kept at the ordinary temperature appears to have been observed in some of the earliest instruments, and to have been at that time attributed to faulty designation of the zero, or "pointing" as it is technically termed.

BELLANI* seems to have been the first to recognise clearly that an ascent does habitually occur, and to have proposed the view, substantially identical with my own, that it is owing to secular changes in the physical nature of glass. Conclusive evidence will be adduced below to prove that atmospheric pressure has no share in producing this ascent.

If we observe at intervals the zero of a thermometer kept at rest at the ordinary temperature, the relation between the time and ascent can be represented graphically by a line which, within the limits of accidental fluctuation, is distinctly continuous and curved. The exact nature of this curve would probably be very difficult to determine. It is not identical for any considerable length, with the ordinary parabola or hyperbola, as has been sometimes supposed. If, however, the values of the remainder of the ascent to a given point be taken for equal intervals of time, they will be found on the whole to diminish by a constant factor. A logarithmic curve with two terms is sufficient to represent, within the limits of experimental error, the ascent of a thermometer's zero with time; the second term being such as to be materially required only in the earliest stages of the ascent. Thus, taking y to denote the remaining ascent, and x successive intervals of time, we have the relation

$$y = \mathrm{A}\alpha^x + \mathrm{B}\beta^x;$$

where $(\mathrm{A}+\mathrm{B})$ represents the total ascent, and α, β, are constants, β being much less than α. There is thus no difficulty in establishing for any given thermometer an equation sufficiently exact for all practical purposes, and probably applicable to bulbs of any shape whatever. It is important to illustrate this equation.

JOULE'S *Results.*—In the "Memoirs of the Manchester Literary and Philosophical Society," xxiii. 292, 293, JOULE gives particulars of nearly twenty-nine years' observations of the zero of a single thermometer, the longest series hitherto recorded by any physicist. It is not stated whether the instrument was kept during this period at the ordinary temperature only. A smooth curve is drawn to represent the observations. One division of the scale corresponds to ·043 C. Taking three years as the value of a unit of time, the equation is

$$y = 8{\cdot}6({\cdot}81)^x + 4{\cdot}9({\cdot}08)^x \text{ in divisions,}$$
$$\text{or } = {\cdot}370({\cdot}81)^x + {\cdot}211({\cdot}08)^x \text{ in degrees.}$$

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* Cited by KÄMTZ, *Schweigger's Journal*, xl. p. 200, where a historical resumé is given of the entire subject to the year 1824. A later exhaustive survey has been written by EGEN, *Pogg. Ann.* xi. p. 276, *et seq.*

TABLE II.

x.	*y* Found.	*y* Calc.
·0	—	—
·60	·344	·374
1·24	·297	·297
1·32	·284	·288
2·93	·202	·198
3·99	·172	·159
5·21	·103	·120
7·63	·073	·073
9·60	·043	·052
Probable error of a single comparison, . . .		·010

In this, as in all cases to be hereafter referred to, the calculated number is taken from a graphic curve accurately representing the equation.

The following results refer to three thermometers, V, V_1, DM, observed by DESPRETZ.* The instruments were constructed in the year 1832; when the experiments commenced they were full of air.

The equations are

$$y_{\mathrm{V}} = {\cdot}300({\cdot}8941)^x + {\cdot}200({\cdot}060)^x,$$

$$y_{\mathrm{V}_1} = {\cdot}319({\cdot}8945)^x + {\cdot}161({\cdot}031)^x,$$

$$y_{\mathrm{DM}} = {\cdot}242({\cdot}8670)^x + {\cdot}358({\cdot}042)^x.$$

The unit of x is 100 days.

TABLE III.

x.	V Found.	V Calc.	*x*.	V_1 Found.	V_1 Calc.	*x*.	DM Found.	DM Calc.
0·00	0·50	—	[The same values as for V.]	·48	—	0	·600	—
0·70	·30	·300		·30	·313	1·49	·190	·198
0·95	·28	·297		·28	·293	5·11	·140	·116
1·28	·28	·266		·28	·278	6·23	·120	·099
2·20	·21	·238		·26	·260	8·89	·080	·067
5·86	·13	·155		·15	·167	10·57	·000	·053
5·98	·15	·153		·17	·164			
9·60	·13	·150		·13	·110			
11·28	·08	·087		·09	·091			
11·55	·08	·086		·06	·088			
14·83	·08	·061		·06	·059			
18·20	·04	·039		·03	·042			
18·24	·03	·039		·03	·042			
18·36	·04	·039		·03	·041			
19·39	·06	·033		·03	·036			
19·58	·08	·033		·06	·035			
Probable error of a single comparison,		·014	...	...	·010	...	...	·021

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* *Ann. Ch. Phys.* lxiv. 316, 317.

The above probable errors include the periodical summer depression and winter ascent; doubtless due, as DESPRETZ first remarked, to the effect of temperature. Thermometer (DM) appears to have been rather irregular in its indications; (AE) and B, which were examined at the same time with it, gave far too erratic numbers for any attempt at reduction.

The following experiments on thermometers 20, 50, 101, and 454 were conducted by myself. All the instruments had cylindrical bulbs; they were all vacuous, and had just been heated to 100°, with the exception of 20, which had just been opened. The unit of x is 30 days. The equations are—

$$y_{20} = \cdot 214(\cdot 7565)^x + \cdot 260(\cdot 008)^x,$$
$$y_{50} = \cdot 159(\cdot 8300)^x + \cdot 151(\cdot 080)^x,$$
$$y_{101} = \cdot 144(\cdot 88116)^x + \cdot 046(\cdot 4534)^x,$$
$$y_{454} = \cdot 0545(\cdot 8840)^x + \cdot 116(\cdot 112)^x.$$

TABLE IV.

x.	Therm. 20 Found.	Therm. 20 Calc.	x.	Therm. 50 Found.	Therm. 50 Calc.	x.	Therm. 101 Found.	Therm. 101 Calc.	x.	Therm. 454 Found.	Therm. 454 Calc.
0·00	—	—	0·00	—	—	0·00	—	—	0·00	·170	—
0·30	·209	·247	0·33	·178	·214	1·00	·134	·148	0·70	·067	·074
0·70	·180	·185	0·93	·146	·149	2·00	·116	·121	1·67	·048	·043
1·73	·090	·131	1·67	·147	·118	4·00	·082	·089	2·67	·030	·035
2·67	·139	·103	3·33	·089	·086	5·00	·076	·077	4·07	·030	·028
2·87	·090	·098	6·67	·047	·046	6·00	·068	·068	8·07	·026	·014
5·17	·090	·050	11·47	·000	·019	7·00	·073	·060	13·43	·000	·005
6·87	·027	·030				17·03	·009	·016			
10·47	·008	·011				21·03	·021	·010			
Probable error of one comparison, .		+·020	...	...	·015	...	...	·006	...	...	·005

Observations with thermometer 20, before opening, had furnished the following equation,—

$$y = \cdot 212(\cdot 7373)^x + \cdot 256(\cdot 0430)^x,$$

the unit of x being 10 days. A comparison between theory and experiment is given in Table V.

TABLE V.

x.	Therm. 20 Found.	Therm. 20 Calc.
0·0	·468	...
0·3	·259	·283
0·5	·204	·235
1·0	·161	·167
2·1	·168	·112
5·0	·021	·046
8·0	·050	·018
8·7	·003	·014
Probable error of one comparison,		·022

Thermometers 500, 501, and 502 had nearly spherical bulbs, whose mean diameters were respectively about 9·16, 10·54, and 11·67 millimetres. They were kept, throughout the observations, in an upright position. The observations themselves commenced very shortly after the customary immersion in boiling water. The equations are—

$$y_{500} = \cdot 247(\cdot 92125)^x + \cdot 220(\cdot 0\dot{4}\dot{5})^x,$$
$$y_{501} = \cdot 210(\cdot 86375)^x + \cdot 200(\cdot 03838)^x,$$
$$y_{502} = \cdot 268(\cdot 90936)^x + \cdot 243(\cdot 14482)^x,$$

the unit of x being 30 days.

TABLE VI.

x.	Therm. 500 Found.	Therm. 500 Calc.	Therm. 501 Found.	Therm. 501 Calc.	Therm. 502 Found.	Therm. 502 Calc.
0	·511	·511	·467	·467	·414	·410
1	·261	·278	·217	·238	·155	·189
2	·225	·226	·205	·210	·155	·157
3	·212	·202	·204	·193	·132	·135
4	·167	·183	·153	·178	·063	·117
5	·164	·166	·160	·164	·098	·101
5	·147	·151	·128	·151	·072	·087
7	·140	·137	·144	·139	·041	·075
8	·133	·125	·119	·128	·037	·065
9	·110	·114	·118	·118	·054	·056
10	·111	·104	·133	·109	·075	·049
20	·032	·040	·073	·047	– ·010	·011
21	·041	·036	·041	·044	– ·010	·010
Probable error of one comparison,		·006	...	·011	...	·017

Movement of the Zero with Temperature.

It has long been known that the immersion of a thermometer into boiling water almost invariably lowers the zero. The only consecutive series of observations of the effect of temperature that I have been able to find is due to HENRICI.* His results are readily comprised in the equation

$$y=2{\cdot}100({\cdot}981)^x-{\cdot}099(1{\cdot}360)^x,$$

y being the total remaining ascent, and the unit of x being 10° C. The starting-point of the observations was 50° C.; and depressions were consecutively observed at every 10° to 100°.

TABLE VII.

x.	Zero Observed.	y.	y Calc.
0	0·00	2·00	—
1	−0·10	1·90	1·92
3	−0·25	1·75	1·73
4	−0·40	1·60	1·61
5	−0·60	1·40	1·45
Probable error of a single comparison, .			·023

The depression at 100° in HENRICI's instrument is by far the largest at present recorded. It can easily be shown from the equation that $y=0$ when $x=9{\cdot}35$; so that the zero in this case would have begun to *rise* after immersion of the bulb in a bath at 143°·5.

The following numbers were obtained with thermometers 455, 3 and *c*, all of which had cylindrical bulbs. The results for thermometer 3 are given in terms of its scale, one division of which was equal to 0°·280. The equations are—

$$\begin{aligned} y_{455} &= 2{\cdot}869(\ {\cdot}998\ )^x-{\cdot}143(1{\cdot}324)^x\,, \\ y_3 &= 4{\cdot}723(1{\cdot}006\ )^x-{\cdot}723(1{\cdot}1964)^x\,, \\ y_c &= 1{\cdot}112(\ {\cdot}9986)^x-{\cdot}112(1{\cdot}299)^x\,. \end{aligned}$$

The values of a unit of x being respectively 13°, 20°, and 38°.

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* *Pogg. Ann.* l. 251.

TABLE VIII.

x.	y_{455} Found.	y_{455} Calc.	x.	y_3 Found.	y_3 Calc.	x.	y_c Found.	y_c Calc.
0·00	—	2·726	0	—	4·000	0·00	—	1·000
1·05	2·695	2·673	1	3·912	3·886	1·35	·968	·951
2·61	2·567	2·558	2	3·750	3·745	2·76	·872	·878
3·12	2·353	2·509	3	3·567	3·570	3·87	·795	·799
4·05	2·209	2·412	4	3·340	3·356	5·03	·688	·686
5·02	2·264	2·256						
6·00	2·092	2·065						
6·71	1·840	1·891						
7·67	1·590	1·584						
8·28	1·397	1·365						
9·15	1·088	·944						
9·86	·616	·554						
Probable error of a single comparision . . .		0°·057	...	...	0°·003	...	...	0°·007

The starting-point of the observations with thermometer 455 was 168°·6. When in its equation $y=0$, $x=10{\cdot}61$; the ascent under the influence of heat is thus converted into a depression after 306°·5. Similarly, the starting-point for thermometer c was 48°·1. The value of x corresponding to $y=0$ is in this case 8·728; the ascent is therefore converted into a depression after 379°·8. On the other hand, under the influence of a lower range of temperature commencing at 40°, the zero of thermometer 3 descends until $x=10{\cdot}828$, corresponding to 256°·7 C, after which it would begin to rise.

It is evident from these experiments that the zero of an ordinary vacuous mercurial thermometer undergoes three distinct movements under the influence of heat. It is at first *depressed* by the action of temperature varying with each particular case, the mean of the numbers actually obtained being at the upper limit $\frac{(48^\circ\cdot + 143^\circ\cdot 5 + 168^\circ\cdot 6 + 256\cdot 7)}{4} = 154\cdot 2$. The further application of heat causes the zero to *ascend*, the effect in this direction being limited to $\frac{(306\cdot 5 + 379\cdot 8)}{2} = 343^\circ\cdot 2$, after which it again *descends*. The explanation of these phenomena is probably as follows. The first effect of heat on the bulb is ordinary expansion, attended with a " set." The second or further effect is to cause the thin part of the glass to become sufficiently plastic to yield to the influence of barometric pressure, which causes gradual collapse. In the third or final stage, at which the vapour of mercury has a sensible tension, the bulb is enlarged by outward pressure due to that cause, and the zero descends.

If the above view be correct, it would follow that a thermometer open to the air, and kept always in a vertical position, would always exhibit a descending zero; the descent in the first stage being due to expansion and set as before, but, in the later stages, simply to the weight of mercury acting upon a bulb now rendered partially plastic by heat. I cannot find that other investigators have left any record of such an experiment. The following trials were made with thermometer 20, which had been open for five years, and whose zero had been long undisturbed:—

TABLE IX.

Zero (Therm. 20).	Scale.	Depression.
Before experiment	+·262 C.	0·000
After 50°	·134	·128
„ 102	−·058	·320
„ 150	·203	·465
„ 200	·360	·622
„ 250	·547	·809
„ 310	·494	·756
„ 350	·570	·832

The first seven observations were made consecutively on one day, the eighth nearly two days later. The temperatures are not corrected. With the exception of the seventh number, which comes out a little too low, this experimental series is in accordance with theory.

IV. POGGENDORFF'S CORRECTION.

So long ago as 1837[*] POGGENDORFF showed that the mercurial thermometer requires a correction to the following effect. The instrument is completely heated to 100° in order to obtain the upper point. At any other temperature, say 50°, the stem is no longer at 100°, and therefore one-half of the original distance (0°−100°) does not correspond accurately to 50°, but to a somewhat higher temperature. If β be the coefficient of cubical expansion of glass, the correction is made by multiplying the observed reading t by the fraction

$$\frac{1+\beta t}{1+\beta 100}.$$

The effect of this correction is by no means inconsiderable. At 300° it amounts to nearly 2°.[†] When, moreover, this correction is employed, the maximum difference over the range 0°−100° between the mercurial and air thermometers is found to lie, not at 50°, as has been hitherto supposed, but near to 34°,—that is, sixteen units nearer to the axis of differences.

[*] *Pogg. Ann.* xli. 472.

[†] RECKNAGEL, *ibid.* cxxiii. 130 (1864).

V. Comparison of the Mercurial with the Air Thermometer.

It has been shown in Sections I., II., and III. that every mercurial thermometer has its individual peculiarities, so that we cannot construct a table of comparison necessarily applicable to more than one mercurial instrument. The individuality referred to can be readily understood; for Pierre showed long since* that the fault lies more in the bulb than in the stem, and it is clear that no two bulbs can be blown of similar figure, uniform or equal thickness, and identical chemical composition.

The air thermometer, which was at first tried in these investigations, consisted of a horizontal horseshoe-shaped glass reservoir, having a capacity of about 115 cubic centims.; it was closed at one end, and communicated at the other with a capillary tube, which was bent twice at right angles, and carried a stopcock. The reservoir lay in a bath, shortly to be described, in which a constant temperature could be maintained, and the bulb of the mercurial thermometer stood vertically in the centre of figure of the reservoir. The drawing (fig. 3) shows the arrangement of this apparatus. The portion of the capillary tube beyond the stopcock communicated with an excellent mercurial air-pump. Now the reservoir of such an instrument, if placed in ice, should contain a definite proportion of normal dry air; and this, if heated and allowed to partially escape through the stopcock, should remain less in proportion to the rise in temperature. According to this method, the expansion is not measured by pressing up a column of mercury, but by pumping out the air which is residual at a definite temperature.

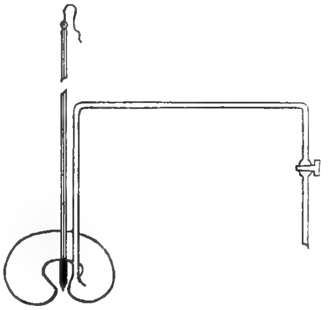

Fig. 3.

It is unnecessary to give minute details respecting the operations conducted with this apparatus, because it proved unsuitable for its purpose. About twenty comparisons were made with thermometer 2 before finally abandoning the method, and the following points were elicited.

In the first place, the following reduced comparisons were made:—

Cubic centims. Air pumped out.	No. of Determinations.	Probable Error of Mean.	Therm. 2.†
80·94	11	·04	115°·84
86·26	11	·06	95·33
91·42	11	·09	72·77
97·88	12	·08	50·35

Zero observations to connect, if possible, the above numbers to a common zero,

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* *Ann. Ch. Phys.* (3) v. 428, *et seq.*

† These numbers have not received Poggendorff's correction.

were soon afterwards undertaken independently, but practically at the above temperatures. These gave

Cubic Centims.	No. of Determinations.	Probable Error of Mean.
115·33	5	·16
116·04	5	·10
115·48	4	·04
115·06	4	·07

After keeping for some time at the ordinary temperature, the zero was 114·02 (probable error of 6 determinations ·08), with a tendency to further contraction. The probable error of measuring the air was inconsiderable.

In this instrument, 1° C. corresponds to about ·3 c.c. It would therefore require to have its volume multiplied about ten times in order to be sufficiently delicate, especially if we have regard to probable error. It would then be too unwieldy to employ; and even were this not the case, its susceptibility to irregular zero variation is a fatal defect.

The method finally adopted was the one ordinarily used, in which the air is not allowed to escape, but caused to remain at constant volume, and raise a column of mercury above a fixed point by its tension. The air-vessel is usually a glass flask; but there is some ground for objecting to a flask, on account of its allowing convection in its contents, and so giving rise to unsteady indications. I have therefore employed a glass helix. The bath in which this stands is of peculiar construction. It consists, as may be seen in fig. 4, of a thin iron pot *a*, placed within a larger one *b*, which is equidistant from all parts of it. The inner pot is wholly enclosed by pure tin tubing, through which an air supply passes from outside the entire apparatus inwards to the bottom, where it bubbles up below the helix, and so acts as an excellent stirrer. The temperatures of the outer bath are integrated by the air which traverses the tin tubing. If a liquid be placed in both pots, a body in the inner pot can only change its temperature very slowly unless the operator chooses to introduce air, or to introduce it at a rapid rate. If, while a moderate current of air is passing, the outer pot is heated for some time, the inner pot will be heated not quite so much; and if the source of heat be now removed, the cold air entering will somewhat cool the outer liquid. A time will thus soon arrive when the outer and inner vessels are exactly at the same temperature, and therefore in the best possible condition for giving a steady heating effect. Using a very strong solution of sodic nitrate in both pots, I have succeeded in keeping a delicate mercurial thermometer almost stationary, for a quarter of an hour, at about 120°. The comparisons of the mercurial with the air thermometer were effected in the following way. The glass helix already referred to carried at its hinder extremity a capillary tube, which was sealed off at *c* after the two pots had been filled for an hour with finely broken ice. The mercury in the pressure tube *h*, *g*, *f*, was brought to *e* on a front capillary tube, *e* being the uppermost division of a small scale, or to some contiguous division. Below *e* the instrument dilates considerably, so as to allow of an excess of air being introduced into the helix by pressure. At *f* there is a joint of marine glue; and at *g*, a lateral tube gives access to the mercury supply, which can be raised or lowered as desired, or cut off, or otherwise adjusted, by a clamp on the india-rubber tubing through which it flows. Between *h* and *g* were cemented two standard half metre scales constructed for me at Kew, and two corrected thermometers; there were thermometers also at *d* and *c*. The bulb of thermometer 2, which was the subject of comparison, occupied the centre of figure of the helix; it was accompanied by a subordinate thermometer for the purpose of calculating the exposure correction. The openings of the two pots were closely screened with tin plates during the experiments.

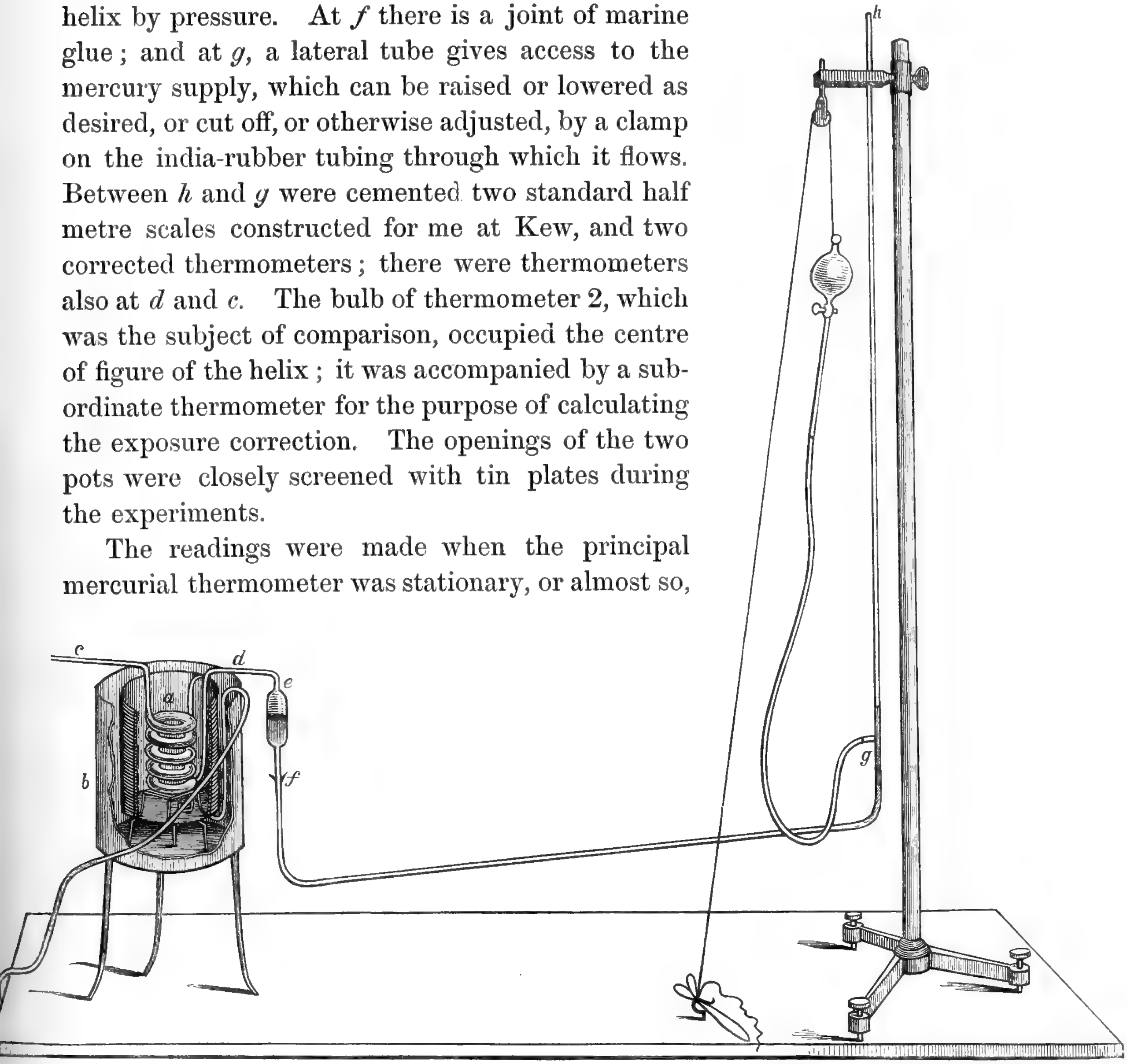

Fig. 4.

The readings were made when the principal mercurial thermometer was stationary, or almost so, some being taking during an ascending, others during a descending phase; the five ancillary thermometers and the pressure were read as nearly as possible at the same time. At every "reading" the exactness of contact of the mercury with *e* was secured by suddenly pinching and relaxing the india-rubber tubing near to g, and otherwise adjusting the mercury as was necessary. About ten "readings" on the average were taken to find a "mean reading," and from this a "single comparison" was deduced. Altogether thirty-three "single comparisons" were made. It was considered advisable to employ two glass helices, whose respective capacities were (1) 71·7 cubic centims. and (2) 62·0 cubic centims. The correction for the barometer was made at Kew; its readings were reduced by Schumacher's tables. The calculations, which were made in accordance with the well-known formula,*

$$T=\frac{H-h+\frac{v}{V}\left\{H\frac{1+\beta t'}{1+at'}-h\frac{1+\beta t}{1+at}\right\}}{a\left[h-\frac{v}{V}\left\{H\frac{1+\beta t'}{1+at'}-h\frac{1+\beta t}{1+at}\right\}\right]-H\beta},$$

and verified, proved extremely tedious. They were all based on a determination of the coefficient of expansion of air, which can of course be readily determined by this instrument from observations at 0° and at the boiling-point of water. As a mean of four closely accordant determinations, the value $\alpha = \cdot 0036772$ was adopted. The results obtained by Magnus, Regnault, and Jolly range from ·0036678 to ·0036645, the higher number having much greater weight. The use of a coefficient determined with the apparatus actually employed in making the thermometer comparisons, destroys a number of small errors which might otherwise have an appreciable influence on the numbers obtained. The numerical results of the comparisons were plotted out on paper, the values of Δt (=Therm. 2−Air therm.) being taken along the ordinate, of therm. 2 along the abscissa. Points 1 and 2 were joined and bisected, points 2 and 3 also joined and bisected, &c.; the bisection points were then similarly treated, and the new lines thus drawn again bisected, &c.; finally, a freehand curve was drawn through the points last arrived at. The following data were then taken from this curve—

Therm. 2.	Δt.
114·00	·066
65·61	·123
31·88	·198

These numbers lead to the equation

$$\Delta t = \cdot 012901t - \cdot 00024937t^2 + \cdot 0000012393t^3,$$

which gives $\Delta t = \cdot 036$ (instead of ·000) when $t = 100°$. Of the three constants on the right hand side, the third, depending on the higher temperatures, is by

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* Wüllner, *Lehrbuch der Experimentalphysik*, iii. 104.

far the most uncertain. I have therefore made in it the alteration necessary to make $\Delta t = \cdot 000$ at 100°, the result is

$$\Delta t = \cdot 012901 t - \cdot 00024937 t^2 + \cdot 0000012036 t^3.$$

The real probable error of a single comparison of calculation with experiment is evidently $\cdot 036 \times \cdot 84 = \cdot 030$, deduced from the arbitrary condition above referred to; the probable error as calculated from all the comparisons below (Table X.) is ·085, a value exceeded by 18 of the actual errors, and not attained by 15 of them.

Series.	t (Merc.)	Δt Found.	Δt Calc.	Δt Found – Δt Calc.
	28·79	+·267	·193	·074
	50·54	−·036	·170	−·206
I.	76·90	+·005	·064	−·059
(Air therm. 1).	112·87	+·226	·010	·216
	25·12	+·048	·186	−·138
II.	48·17	−·008	·176	−·184
(Air therm. 1).	74·78	−·120	·074	−·194
	16·73	+·156	·152	·004
III.	30·29	+·297	·195	·102
(Air therm. 2).	50·70	+·103	·170	−·067
	66·80	+·103	·108	−·005
IV.	29·06	+·246	·193	·053
(Air therm. 2).	54·50	+·215	·157	·058
	67·70	+·170	·103	·067
V.	17·45	+·404	·155	·249
(Air therm. 2).	27·10	+·460	·191	·269
	55·53	+·141	·153	−·012
VI.	67·00	+·104	·107	−·003
(Air therm. 2).	19·25	+·368	·165	·203
	28·86	+·182	·193	−·011
VII.	49·76	+·206	·173	·033
(Air therm. 2).	65·61	+·123	·113	·010
	17·76	+·199	·157	·042
VIII.	28·54	+·343	·235	·108
(Air therm. 2).	49·95	+·131	·172	−·041
	65·77	+·160	·111	·049
IX.	113·64	−·086	·013	−·099
(Air therm. 2).	15·88	+·041	·147	−·106
	27·17	+·283	·190	·093
X.	54·19	+·342	·158	·184
(Air therm. 2).	74·14	+·053	·075	−·022
	97·23	−·034	·003	−·037
	115·57	+·191	·018	·173

Actual errors of the above magnitude occur with about equal frequency in the work of preceding experimenters, and seem to be naturally incidental to such operations. They depend partly upon the fact (first observed by

Recknagel, and amply confirmed by myself) that the contents of the air-reservoir are continually undergoing diminution by escape of air against the mercurial pressure, and can scarcely be depended on for more than a single day.* They may also be in part due to the difficulty experienced by air in leaving, or being returned to, the reservoir through the capillary tube, which is probably nearly always too narrow. The latter fault is capable of easy remedy; but it unfortunately did not occur to me until the experiments were complete, and I have since had no leisure to repeat them with the new condition.

According to the equation expressing the relation between thermometer 2 and the air-thermometer, the maximum difference between the two lies at 34°·47, when it amounts to 0°·198. The numbers on which this equation is based have received Poggendorff's correction.

VI. Compression.

The stem of an ordinary thermometer may be regarded, for all practical purposes, as incompressible. The bulb, however, is always thin, and has yielding sides; it is therefore affected by external pressure.

The first observation with regard to the compression of the bulb appears to have been made by Gourdon, who, according to Egen,† made the experiment of fracturing a thermometer of known positive zero-error. After fracture, the zero fell by a measurable amount. Egen himself repeated this experiment, and obtained the following results with spherical bulbs:—

Thermometer.	V.	VI.	IX.
Depression due to 1 atmosphere, .	·205	·080	·369
Relative thickness of the bulbs, . .	1·5	2·3	1·0

Here the effect evidently tends to be inversely proportional to the thickness of the bulb. Four of my own thermometers were opened, and the zero-depressions observed were—

Thermometer.	500.	501.	502.	20.
Observed depressions, . .	·285	·199	·193	·180
Depressions corrected for the pressure of a little air,	·295	·200	·199	„

Thermometer 20, which was cylindrical, contained no appreciable quantity of air. The other thermometers had spherical bulbs. On the whole, it appears

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* My own experiments were for the most part performed at the rate of a "series" per day.

† *Pogg. Ann.* xi. p. 283 (1827).

that the effect of atmospheric pressure may count for about ·2 in the zero's ascent.

Another mode of investigation consists in ascertaining the alteration of the zero after immersing the bulb in water boiling under different ordinary barometric pressures. I have made a large number of experiments with thermometers 2 and 3 in my collection, and have obtained the following mean relations :—

Thermometer.	2.	3.
Approximate value of 1 atmosphere in degrees,	1·31	0·84

The change of zero due to fluctuation in barometric changes is so slight that I do not place much reliance on these numbers, and am not disposed to recommend the method. EGEN has also reported* the effect of artificial pressure upon a bulb, the bulb in this case lying in the interior of a flexible case, to which a tube containing mercury, and capable of adjustment at various angles for pressure, was securely attached. The following are his numbers :—

Height of Mercury in inches.	Mean Elevation on Scale.	
	Found.	Calculated.
41	59·0	59·0
29	41·6	41·7
21·5	26·6	30·9

The ascent so far is proportional to the pressure.

It appeared advisable to investigate this law under better conditions and a greater range of pressure. Fortunately for this purpose the well-known apparatus devised by ANDREWS for studying the effect of pressure upon gases is available without alteration for thermometers. All that is necessary is to substitute for the gas tube in a duplex apparatus the thermometer which it is desired to compress, the readings in the air tube (corrected as prescribed by ANDREWS) give the pressure. I am indebted to the kindness of Professor Sir WILLIAM THOMSON, D.C.L., F.R.S., for a loan of this instrument.

The thermometer (455) I employed had a cylindrical bulb. Its readings were corrected by its calibration table, and the subtraction of the mean scale reading before and after compression. The temperature rose only ·05 during the experiments. The first eight numbers given below are the means of four closely accordant observations, two of which were made with increasing and

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* *Loc. cit.* 351.

two with decreasing pressure; the ninth comparison is derived from two observations, the tenth from one observation.

Pressure in Atmospheres.		Therm. 455.
Observed.	Calculated.	
49·4	49·58	5·25
58·7	58·74	6·22
68·1	68·10	7·21
77·6	77·44	8·20
87·0	86·79	9·19
96·3	96·14	10·18
105·5	105·58	11·18
114·3	114·27	12·10
124·0	124·28	13·16
133·6	133·73	14·16

Probable error of a single comparison, ·11.

The equation

$$\text{Pressure} = \text{Degrees} \times 9{\cdot}444,$$

on which the above calculation is founded, is derived from all the above experiments, each experiment being "weighted" with the number of observations it included. It is clear, then, that up to about 134 atmospheres the ascent of the mercury in a thermometer's bulb is proportional to the pressure applied, and does not at the higher limit show any indication of a change of law.

XIX.—*Preliminary Note on the Compressibility of Glass.*
By J. Y. BUCHANAN.

The following experiments were undertaken with a view to determine by actual observation the effect produced on solids by hydraulic pressure.

The instrument was constructed according to my directions by Mr MILNE of Milton House, about two years ago, but it is only now that I have been able to devote myself to its application to the purposes for which it was designed. It consists of a hydraulic pump, which communicates with a steel receiver capable of holding instruments of considerable size, and also with a second receiver of peculiar form. This receiver consists essentially of a steel tube, terminated at each end by thick glass tubes fitted tightly. It is tapped at the centre with two holes, the one to establish connection with the pump, and the other to admit a pressure gauge or manometer. The steel tube may be of any length, being limited only by the extent of laboratory accommodation at disposal. The tube which I am using at present has a length of a little over six feet, and an internal diameter of about three-tenths of an inch. The solid to be experimented on must be in the form of a rod or wire, and must, at the ends at least, be sufficiently small to be able to enter the terminal glass tubes, which have a bore of 0·08″ and an external diameter of 0·42″. The length of the solid is such that when it rests in the steel tube its ends are visible in the glass terminations.

When the joints have all been made tight, the experiment is conducted as follows:—A microscope, with micrometer eye-piece, is brought to bear on each end of the rod or wire. These microscopes stand on substantial platforms altogether independent of the hydraulic apparatus. The pressure is now raised to the desired height, as indicated by the manometer, and the ends of the rod are observed, and their position with reference to the micrometer noted. The pressure is then carefully relieved, and a displacement of both ends is seen to take place, and its amplitude noted. The sum of the displacements of the ends, regard being had to their signs, gives the absolute expansion, in the direction of its length, of the glass rod when the pressure at its surface is reduced by the observed amount, and consequently also of the compression when the process is reversed. As in the case of non-crystalline bodies like glass there is no reason why a given pressure should produce a greater effect in one direction than in another, we may put the cubical compression at three times the linear contraction for the same pressure.

As yet I have only experimented on glass, and only on one sort, namely, that made by Messrs FORD & Co. of Edinburgh. It contains 56·29 per cent. of silica, 29·5 per cent. of oxide of lead, 6·52 per cent. potash, 3·36 per cent. soda, 3 per cent. alumina, and 1·05 per cent. lime. I have observed its compressibility up to a pressure of 240 atmospheres, and before proceeding to higher pressures I intend to determine the compressibilities of other solids, especially metals, at pressures up to 240 atmospheres. The reason for taking this course is, that having got two glass tubes to stand this pressure, I am anxious to utilise them as far as possible before risking them at higher pressures.

The pressure in these experiments was measured by a manometer, which consists simply of a mercurial thermometer with a stout bulb, which is immersed in the water under pressure, whilst its stem projects outside. The values of the readings of this instrument were determined by comparing it with a piezometer containing distilled water. This piezometer had been compared with others which had been subjected to the pressure of very considerable and measured columns of water on the sounding line. The mean apparent compressibility of water in glass was thus found to be 0·00004868;* or, multiplying by one thousand, to reduce the number of figures 0·04868 per atmosphere at temperatures from 1° to 4° C.

The manometer (No. 2) was compared with this piezometer. The temperature of the manometer was 12·5° C., while the piezometer was enveloped in ice in the receiver. The ice was thus melting under the same pressure as the instrument was undergoing, consequently the piezometer was not exposed really to precisely the same temperature at each succeeding experiment. For our present purpose, the effect of the possible variation in volume due to this thermic cause is negligeable, and we assume that the indications of our piezometer are comparable with those obtained in deep ocean waters. In a future communication I hope to return to this point.

In Table I. we have in the first column the number of observations at each approximately identical pressure from which the average values of the manometer reading under A, and of the piezometer indication under H are computed. Manometer No. 2, when treated simply as a thermometer, showed at atmospheric pressure a rise of one division for a rise of 0·233° C. in temperature. Piezometer K, No. 4, was filled with distilled water, and contained 7·74 cub. centimetres at 0° and atmospheric pressure. It is made of FORD's glass, though not drawn at the same date as the experimental rod.

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* Proc. Royal Society of London, 1876, p. 162.

TABLE I.—*Comparison of Manometer No.* 2 *at* 12·5° *C. with Piezometer K, No.* 4, *in Ice melting under Pressure.*

Piezometer K, No. 4, contains at atmospheric pressure 7·74 cub. cents. of water.	Number of Observations meaned.	Pressure in Divisions of Manometer No. 2.	Apparent Contraction of Water per thousand in Piezometer K, No. 4.
		A	H
Temperature of manometer, 12·55° C. . . . Piezometer immersed in ice melting under pressure represented by A. Probable temperature varying from −1° to 0° C. . . .	4	26·08	4·0228
	4	30·28	4·6534
	1	36·20	5·5972
	5	40·08	6·1045
	3	50·08	7·6043
	3	60·20	9·1057
	3	70·08	10·5163
Total number of observations	23		
Mean reading of manometer		43·61	
Mean apparent contraction of water in piezometer			6·6495

Dividing the mean apparent contraction of the water in the piezometer by the apparent compressibility of water in glass 0·04868, we have for the pressure corresponding to a rise of 43·61 divisions on manometer No. 2 at 12·5° C.

$$P = \frac{H}{0{\cdot}04868} = \frac{6{\cdot}6495}{0{\cdot}04868},$$

$$= 136{\cdot}6 \text{ atmospheres.}$$

But this pressure produces a rise of 43·61 divisions on manometer No. 2. We have thus for the value of one division on the manometer

$$a = \frac{136{\cdot}6}{43{\cdot}61},$$

$$= 3{\cdot}132.$$

Hence, to convert readings of manometer No. 2 into atmospheres, we have to multiply by 3·132, the difference of the manometer reading under pressure and that at atmospheric pressure.

In another series of experiments piezometer K, No. 4, was compared with manometer No. 2, both being at a temperature of 12·5° C., and the following results were obtained as the mean of nineteen observations :—

Mean rise of manometer No. 2 (A) . . .	41·35	divisions.
Mean apparent contraction per thousand of water in piezometer K, No. 4 (H)	5·8782	,,

But from the results in Table I. we have for the pressure in atmospheres

$$P = 3{\cdot}132 \times A = 3{\cdot}132 \times 41{\cdot}35,$$

$$= 129{\cdot}5 \text{ atmospheres,}$$

and the apparent compressibility of water in glass at this temperature (12·5° C.) in volumes per thousand per atmosphere, is

$$M = \frac{H}{P} = \frac{5{\cdot}8782}{129{\cdot}5},$$

$$= 0{\cdot}04539.$$

We see, then, that at pressures up to 240 atmospheres the property peculiar to water of diminishing in compressibility with rise of temperature is preserved unimpaired, and the amount of change corresponds closely with that found at low pressures in the experiments of Regnault and Grassi.

In Table II. the details of the experiments on the effects of pressure on the glass rod are given. The length of the rod from point to point was 75·05 inches, at the temperature of the laboratory, 13° C. Its diameter was 0·28″, and was very uniform. The weight of the rod was 209·5 grammes. The substance of the rod was remarkably homogeneous, there being a complete absence of air-threads.

The micrometers used were, at the east end a photographic copy of Hartnack's eye-piece micrometer, and at the west end one of Merz's. They were both compared, and the value of their divisions, as used, determined by comparison with a stage micrometer of Smith & Beck, obligingly lent to me by my friend Dr William Robertson, who had very carefully verified its graduation. It was remarkable as a coincidence that the values of the divisions turned out to be identical in both, namely, 0·000417″.

Under A we have the manometric pressures, under B and C the micrometric determinations of the expansion at the east and the west end respectively, and under D the sum B and C, or the total expansion of the rod. It will be seen that while the values of D, or the total expansion, are very concordant in each series, those of B and C individually are not always so, the excess being sometimes at the one end and sometimes at the other. The effect of the rise of pressure is to extend the containing tube, and to compress the contained rod. On the relief of pressure the tube shortens again, and the rod recovers its length, and there is necessarily a sliding of the one on the other, and it depends entirely on minute local circumstances whether the rod finds it easier to return to its original relative position or to another. In some experiments made previously to the date of those quoted in Table II., the rod had greater freedom of motion longitudinally, and it happened several times that it crept bodily to the one end, necessitating the opening of the apparatus to replace it in a position suited to observation. Afterwards stops were placed in the tube, which, while setting limits to the crawling motion, did not in any way interfere with the expansion and contraction. The results of these previous experiments are not included in the Table, because they were merely tentative in order to learn the details of the kind of experimentation; and further, because in the microscope at the east end the power used was very low, and the micrometer insufficiently delicate.

In the left hand columns the individual experimental data are given. The arithmetical means of the manometric pressures and of the total micrometric expansions are taken for each series. These mean results are then further developed on the right hand side of the table. First the temperature is given, T. This remains always very constant, as it was the temperature of the room, which varied very little. It was further controlled between each experiment by the reading of the manometer when the pressure was reduced to that of the atmosphere. The pressure in atmospheres (P) is obtained, as explained above, by multiplying the manometric pressure (A) by 3·13,

$$P = 3{\cdot}13 \times A.$$

The linear compression (F) for pressure (P) is given by multiplying the micrometric expansion by the value of a division, or 0·000417″,

$$F = 0{\cdot}000417 \times D,$$

$$H = \frac{10^6}{75{\cdot}05} F.$$

H is the linear compression in inches of a rod one million inches long for pressure P.

$$K = \frac{H}{P}$$

is the same per atmosphere or the linear compressibility of the glass.

$$N = 3K$$

is the cubical compressibility of the same glass.

These results are summarised in Table III.

TABLE II.—*Details of Experiments on the Compression produced on a Glass Rod by Pressures up to 240 Atmospheres.*

Series.	Pressure. Reading of Manometer No. 2.		Pressure. Divisions of Manometer No. 2.	Expansion in Micrometer Divisions.			Length of Glass Rod . . 75·05 inches. Diameter of do. . . . 0·28 ,, Weight of do. . . . 209·5 grammes. 1 Division of Micrometer . . =0·000417″			
				East End.	West End.	Total.				
	A_1	A_2	(A_1-A_2) A	B	C	B+C= D				
I.	33·0	13·0	20	5	6	11	Date, 3d June 1880 .			
	33·0	13·1	19·9	5	6	11	Temperature (Centigrade)	T	…	13·5°
	35·0	13·8	21·2	6	6	12	Number of observations	…	…	8
	34·0	13·9	20·1	7	5	12	Pressure in atmospheres	P	A × 3·13	64
	34·0	13·9	20·1	5	6	11	Linear compression . .	F	0·000417D	0·0047
	33·7	14·0	19·7	4	6	10	Do. per million . . .	H	$\frac{10^6}{75\cdot05}F$	62·6
	35·5	14·0	21·5	6	5	11				
	34·8	14·1	20·7	5	6	11	Do. do. per atmosphere	K	$\frac{H}{P}$	0·983
			20·40			11·13	Cubical compression, per 10^6 per atmosphere	N	3K	2·949
II.	51·5	14·1	37·4	9	10	19	Date, 3d June 1880 .			
	51·7	14·2	37·5	9	11	20	Temperature (Centigrade)	T	…	13·7°
	52·0	14·2	37·8	9	11·5	20·5	Number of observations	…	…	8
	53·0	14·8	38·2	9	11	20	Pressure in atmospheres	P	A × 3·13	118
	52·3	14·9	37·4	9·5	10	19·5	Linear compression . .	F	0·000417D	0·00826
	52·2	15·0	37·2	16	4	20	Do. per million . . .	H	$\frac{10^6}{75\cdot05}F$	110·0
	52·1	15·0	37·1	15	5	20				
	52·5	15·1	37·4	15	4·5	19·5	Do. do. per atmosphere	K	$\frac{H}{P}$	0·942
			37·50			19·81	Cubical compression, per 10^6 per atmosphere	N	3K	2·826
III.	61·0	11·0	50·0	11	15	26	Date, 4th June 1880 .			
	61·0	11·0	50·0	13	14	27	Temperature (Centigrade)	T	…	12·8°
	61·0	11·1	49·9	12	16	28	Number of observations	…	…	13
	61·0	11·1	49·9	22	3·5	25·5	Pressure in atmospheres	P	A × 3·13	158
	61·5	11·2	50·3	15·5	11	26·5	Linear compression . .	F	0·000417D	0·01119
	63·0	11·2	51·8	15	13	28				
	62·2	11·5	50·7	19	8	27	Do. per million . . .	H	$\frac{10^6}{75\cdot05}F$	149·1
	63·0	11·8	51·2	15	12	27				
	62·8	11·9	50·9	22	6	28	Do. do. per atmosphere	K	$\frac{H}{P}$	0·946
	62·0	11·9	50·1	13	13	26				
	62·3	12·0	50·3	18	8	26	Cubical compression, per 10^6 per atmosphere	N	3K	2·838
	62·3	12·0	50·3	23	5	28				
	63·0	12·0	51·0	14	12	26				
			50·49			26·84				

TABLE II.—*continued.*

Series.	Pressure. Reading of Manometer No. 2.		Pressure. Divisions of Manometer No. 2.	Expansion in Manometer Divisions.			Length of Glass Rod . . . Diameter of do. . . . Weight of do. . . . 1 Division of Macrometer . .		75·05 inches. 0·28 ,, 209·5 grammes. $=0{\cdot}000417''$
				East End.	West End.	Total.			
	A_1	A_2	$(A_1 - A_2)$ A	B	C	B+C= D			
IV.	69·8	12·4	57·4	15	17	32	Date, 4th June 1880.		
	69·8	12·6	57·2	32	0	32	Temperature (Centigrade)	T	...	12·5°
	69·7	12·6	57·1	27	4	31	Number of observations	...	...	8
	69·5	12·8	56·7	19	13	32	Pressure in atmospheres	P	$A \times 3{\cdot}13$	177
	69·8	13·1	56·7	19	13	32	Linear compression .	F	$0{\cdot}000417\,D$	0·01334
	69·1	13·0	56·1	20	12	32	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	177·8
	69·5	13·0	56·5	14	18	32	Do. do. per atmosphere	K	$\frac{H}{P}$	1·002
	70·3	13·0	57·3	16	17	33	Cubical compression, per 10^6 per atmosphere	N	$3K$	3·006
			56·88			32·00				
V.	76·3	13·3	63·0	27	9	36	Date, 7th June 1880.			
	75·5	13·8	61·7	17	18·5	35·5	Temperature (Centigrade)	T	...	12·5°
	76·8	13·8	63·0	18	18·0	36	Number of observations	...	...	10
	77·0	13·9	63·1	18	18·0	36	Pressure in atmospheres	P	$A \times 3{\cdot}13$	197
	77·0	14·0	63·0	15	20·0	35	Linear compression . .	F	$0{\cdot}000417\,D$	0·1475
	77·6	14·0	63·6	17	19·0	36	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	0·1966
	77·0	14·0	63·0	16	18·0	34	Do. do. per atmosphere	K	$\frac{H}{P}$	0·998
	77·3	14·0	63·3	16	18·5	34·5	Cubical compression, per 10^6 per atmosphere	N	$3K$	2·994
	77·1	14·1	63·0	16	20·5	36·5				
	77·1	14·1	63·0	14	20·5	34·5				
			62·97			35·39				
VI.	43·0	8·2	34·8	10	8	18	Date, 7th June 1880.			
	42·9	8·3	34·6	12	6	18	Temperature (Centigrade)	T	...	12·2°
	43·0	8·6	34·4	14·5	3	17·5	Number of observations	...	...	11
	43·6	8·7	34·9	14·0	4	18	Pressure in atmospheres	P	$A \times 3{\cdot}13$	109
	43·8	8·9	34·9	14·5	3	17·5	Linear compression . .	F	$0{\cdot}000417\,D$	0·00753
	43·8	8·9	34·9	11·5	5·5(−)	17·0	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	100·3
	43·8	9·0	34·8	11·0	7·0	18	Do. do. per atmosphere	K	$\frac{H}{P}$	0·924
	44·2	9·0	35·2	10·5(+)	8·0	18·5	Cubical compression, per 10^6 per atmosphere	N	$3K$	2·772
	44·0	9·1	34·9	10·0	9·0(+)	19				
	43·9	9·2	34·7	9·0	10·0	19				
	44·0	9·2	34·8	9·5	8·5	18				
			34·81			18·05				
VII.	59·4	9·2	50·2	11·5	14	25·5	Date, 7th June 1880.			
	59·8	9·3	50·5	18	8·5	26·5	Temperature (Centigrade)	T	...	12·3°
	60·0	9·6	50·4	16	11	27	Number of observations	...	...	10
	59·2	9·8	49·4	12	15·5	27·5	Pressure in atmospheres	P	$A \times 3{\cdot}13$	157
	60·0	9·8	50·2	12	15·5	27·5	Linear compression . .	F	$0{\cdot}000417\,D$	0·01126
	59·9	9·9	50·0	12	14	26·0	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	150·0
	60·4	9·9	50·5	16	11·5	27·5	Do. do. per atmosphere	K	$\frac{H}{P}$	0·957
	60·0	10·0	50·0	16	12	28·0	Cubical compression, per 10^6 per atmosphere	N	$3K$	2·871
	61·0	10·0	51·0	15	12·5	27·5				
	60·8	10·0	50·8	7	20	27				
			50·30			27·00				

TABLE II.—*continued.*

Series.	Pressure. Reading of Manometer No. 2.		Pressure. Divisions of Manometer No. 2.	Expansion of Micrometer Divisions.			Length of Glass Rod . . . 75·05 inches. Diameter of do. . . . 0·28 ,, Weight of do. . . . 209·5 grammes. 1 Division of Macrometer . =0·000417″			
				East End.	West End.	Total.				
	A_1	A_2	(A_1-A_2) A	B	C	B+C= D				
VIII.	72·0	10·0	62·0	7	26	33	Date, 7th June 1880.			
	72·8	10·1	62·7	18	16	34	Temperature (Centigrade)	T	...	12·5°
	72·6	10·2	62·4	14	20·5	34·5	Number of observations	...	...	7
	71·7	10·3	61·4	16	17	33	Pressure in atmosphere	P	A × 3·13	195
	73·0	10·4	62·6	9	25	34	Linear compression . .	F	0·000417 D	0·0140
	73·0	10·7	62·3	10·5	23	33·5				
	73·0	10·9	62·1	10	24	34	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	187·2
			62·21			33·71	Do. per atmosphere . .	K	$\frac{H}{P}$	0·961
							Cubical compression, per 10⁶ per atmosphere	N	3K	2·882
IX.	79·8	11·1	68·7	11	26·5	37·5	Date, 7th June 1880.			
	80·6	11·2	69·4	12	25	37	Temperature (Centigrade)	T	...	12·8°
	80·5	11·2	69·3	11	25·5	36·5	Number of observations	...	...	10
	80·5	11·4	69·1	12	26	38	Pressure in atmospheres	P	A × 3·13	216
	80·8	11·4	69·4	11	27·5	38·5	Linear compression . .	F	0·000417 D	0·01547
	80·5	11·5	69·0	20	15·5	35·5				
	80·5	11·6	68·9	13	24	37	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	206·1
	80·5	11·8	68·7	20	17	37				
	80·0	11·8	68·2	11	25·5	36·5	Do. do. per atmosphere	K	$\frac{H}{P}$	0·957
	80·5	11·8	68·7	12	25·5	37·5	Cubical compression, per 10⁶ per atmosphere	N	3K	2·870
			68·94			37·10				
X.	88·0	12·0	76·0	11	29	40	Date, 7th June 1880.			
	89·9	12·1	77·8	11	29	40	Temperature (Centigrade)	T	...	12·9°
	88·9	12·2	76·7	11	28	39	Number of observations	...	...	6
	88·5	12·2	76·3	14	27·5	41·5	Pressures in atmospheres	P	A × 3·13	240
	88·5	12·3	76·2	17	22·5	39·5	Linear compression . .	F	0·000417 D	0·01671
	88·5	12·3	76·2	11·5	29	40·5	Do. per million . . .	H	$\frac{10^6}{75{\cdot}05}F$	222·6
			76·53			40·08	Do. do. per atmosphere	K	$\frac{H}{P}$	0·929
							Cubical compression, per 10⁶ per atmosphere	N	3K	2·786

Table III.—*Summary of Experiments made on the 3d, 4th, and 7th June* 1880, *on the Compression produced on a Glass Rod by Pressures up to* 240 *Atmospheres.*

Series No.	Number of Observations.	Temperature, Centigrade.	Pressure in Atmospheres.	Linear Compression.			Cubical Compression per Million per Atmosphere.	Greatest Deviation of F from the Mean.	Greatest Deviation per cent. from Mean.
				Inch.	Per Million.	Per Million per Atmo.			
		T	P	F	H	K	N	Q	$\frac{100Q}{F}$ = R
1	8	13·5°	64	0·0047″	62·6	0·98	3·0	0·00047″	10·0
6	11	12·2	109	0·0075	100	0·92	2·8	44	5·8
2	8	13·7	118	0·0083	110	0·94	2·9	34	4·1
7	10	12·3	157	0·0113	150	0·96	2·9	42	3·7
3	13	12·8	158	0·0112	149	0·95	2·9	56	5·0
4	8	12·5	177	0·0133	178	1·00	3·0	42	3·2
8	7	12·5	195	0·0140	187	0·96	2·9	33	2·3
5	10	12·5	197	0·0148	197	1·00	3·0	46	3·1
9	10	12·8	216	0·0155	206	0·96	2·9	58	3·7
10	6	12·9	240	0·0167	223	0·93	2·8	59	3·5
						0·960	2·92		

Two columns Q and R are added. Q gives the greatest absolute deviation from the mean total expansion in any series, R gives the deviation per cent.

In the observations recorded I made no attempt to subdivide the micrometer divisions further than to estimate a half. As the micrometer readings are not affected directly by the pressure, the deviation per cent. should be, as it is, less the higher the pressure; and there is no doubt that the higher the pressure is the greater is the accuracy of the observation. The only way in which the pressure affects the reading of the micrometer is that when it is sufficiently high it produces a microscopic distortion of the tube, which throws the point of the rod very slightly out of focus. This is remedied by a slight touch of the fine adjustment screw of the microscope.

The general result of these experiments is that the linear compressibility of the glass experimented on is 0·96, and its cubical compressibility 2·92 per million.

Grassi* gives as the means of his observations at pressures up to ten atmospheres—Glass, 2·25; crystal, 2·804 and 2·8584. The agreement between the two is very close.

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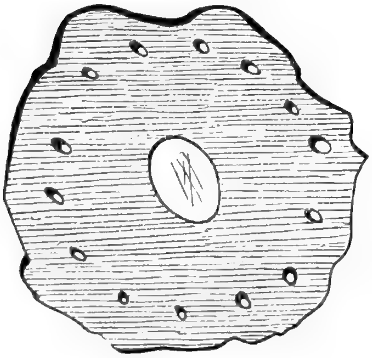
* Ann. Chim. Phys. (1851) [3], 31, p. 474.

We have then for the apparent compressibility of water in glass at 2·5° C. 48·68 per million per atmosphere. Adding 2·92 for the compressibility of glass, we have for the compressibility of water at 2·5° C. 51·60. Similarly at 12·5° C. we have 45·39 for the apparent, and 48·31 for the real compressibility. GRASSI gives the following values for the true compressibility of water at various temperatures:—At 1·5° C.—51·5; at 4·1°—49·9; mean—50·7. At 10·8° C.—48·0; at 13·4°—47·7; mean—47·8. My results agree very closely with these.

Before concluding, I would call attention to a very curious phenomenon, which I have never seen noticed, namely, the peculiar *noise* which accompanies the relief of pressure in a mixture of ice and water. In comparing the piezometer K, No. 4, in melting ice with the manometer at 12·5° C., I proceeded gradually from lower to higher pressures. When the pressure which was relieved was 100 or 120 atmospheres, I thought I noticed a slight noise. On raising the pressure higher the noise became more and more distinct, until when the pressure relieved was over 200 atmospheres, it was distinctly audible at a distance of five or six feet. It resembles the noise produced by bending a piece of tin backwards and forwards, and is markedly intensified by accelerating the relief, just as the noise made by blowing off steam is intensified by enlarging the outlet. When the relief valve is opened very carefully it whispers gently but very distinctly, till the pressure is all down. If opened comparatively briskly, but still with great care, the noise is comparatively loud, but more rapidly used up. I forbear making any reflections until I have been able to study this phenomenon more closely.

Pieces of clear ice which had been subjected to high pressure in the receiver were finely laminated in parallel planes. In each plane there was a central patch surrounded near the sides of the block by a ring of spherules. The annexed figure gives an idea of the arrangement. The size of the spherules is greatly exaggerated.



The lamination of ice by pressure in one direction is well known. I am not aware that its production by pressure in all directions has been noticed.

XX.—*On the Variation with Temperature of the Electrical Resistance of Wires of certain Alloys.* By Professor J. G. MacGregor, D.Sc., and C. G. Knott, D.Sc.

(Read 19th July 1880.)

The alloys which we used in the following experiments were in the form of very thin hard-drawn wires,—the same as those whose thermo-electric properties we described in a paper published in the Transactions of this Society in 1877.* They were prepared by Messrs. Johnson and Matthey of Hatton Garden, London. In giving their constitution we rely upon the authority of the manufacturers, as the quantities we had were too small to admit of our having them analysed.

The thin alloy wires were successively soldered to thick copper wires, by means of which they were placed in one of the arms of a Wheatstone's Bridge. The other three arms were composed of resistance coils, made by Elliott Brothers, London, and arranged in the dial form. In the bridge itself Thomson's "dead beat" galvanometer was used as galvanoscope. The thick copper wires were so arranged that the alloy wire occupied the central part of a copper vessel, which was full of oil. As the alloy wires were in all cases short, the vessel required to be only about 5 inches in diameter. A thermometer hung so that its bulb was in the oil at the same level as the alloy wire and very near it. The vessel contained also a stirrer, and was heated by a Bunsen burner.

We found that by careful heating and stirring we could bring the oil to a very nearly permanent state as to temperature. When by these means the thermometer had been brought to give for a considerable time the same indication, the temperature was read off, and the resistance finally determined at the same moment.

As, by the Wheatstone's bridge method, resistance can be determined with very great accuracy, the chief sources of error in these experiments lay in the determination of temperature. To avoid these care must be taken to ensure equilibrium of temperature between the wire, oil, and thermometer, and accuracy in the thermometer. As our wires were exceedingly thin (one or two inches having in all cases a resistance of several ohms) they would undoubtedly in a very short time take the same temperature as the oil. As they were

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* Trans. Roy. Soc. Edin., vol. xxviii. (1877), p. 321.

soldered to thick copper wires, however, there was danger that the heat would thus be conducted rapidly away, and their ends thereby rendered cooler than their middle parts. To prevent this the alloy was always sunk about five inches beneath the surface of the oil, and the oil kept for a considerable time at approximately the temperature at which the resistance was to be measured. With these precautions, we considered ourselves justified in assuming that the lower ends of the thick copper wires had the same temperature as the oil at the moment of measuring the resistance.

That we might be sure that the thermometer had the same temperature as the oil, it was necessary (as it was not possible to keep the oil for very long times at permanent temperatures) to use a thermometer with as small a bulb as sufficient accuracy in readings would allow. We chose one which would easily give accurate readings to one-tenth of a degree Centigrade. We determined its errors between the limits of temperature for which we used it by comparing it carefully with another thermometer whose errors had been determined at Kew. Our temperature limits were about 16° C. and 150° C.

The copper connections were so thick that their resistance and the variation of the resistance of those parts of them which were heated could be neglected. We satisfied ourselves by special experiments, the details of which need not be given, that a thin lamina of the oil which we used had a resistance greater than we could measure with the coils at our disposal, and a conductivity therefore which might be neglected.

Having only very small quantities of the alloys we could not determine their coefficients of expansion. We are therefore unable to eliminate the change of resistance due to the change of dimensions of the wires. If we assume the mean coefficient of expansion per degree between 0° and 150° to be ·00002, then a wire whose resistance at 0° was unity would, through change of dimensions alone, be only about ·997 at 150°. For all alloys whose coefficients of expansion are positive the increase in the specific resistance of the alloy is always greater than the increase of the resistance of the wire which is measured. But without the coefficient of expansion it cannot be determined. In this paper, then, we discuss the variation of the resistance *of wires* of certain alloys.

Iron-Gold Alloy.

Table I. gives the results of experiments with the only alloy of iron and gold which we had at our disposal. It contained 5 per cent. by mass of iron, or approximately 11·9 per cent. by volume. The first column gives successive temperatures, the second the corresponding observed resistances of the wire.

TABLE I.

Temperature.	Resistance.	
	Observed.	Calculated.
16·8° C.	12·33	12·340
47·2	12·47	12·471
65·4	12·55	12·543
89·3	12·64	12·635
104·2	12·685	12·689
118·0	12·74	12·738
127·6	12·77	12·771
147·4	12·84	12·836

These results are found capable of being very accurately represented by the following formula, in which R stands for resistance t for temperature.

$$R = 12{\cdot}265 + {\cdot}0045625t - {\cdot}0000046875t^2.$$

The numbers of the third column are calculated by means of this formula, and show a satisfactory agreement with those of the second. For a wire therefore whose resistance at 0° C. would be unity (r representing the resistance of such wire, and the formula being supposed to hold at 0°),

$$r = 1 + {\cdot}00037198t - {\cdot}00000038217t^2.$$

Hence, if k represents the conductivity of such wire,

$$k = 1 - {\cdot}00037198t + {\cdot}00000052054t^2.$$

With this result we may compare the formula which MATTHIESSEN and VOGT* give for an alloy of the same metals 10·96 per cent. by volume of which is iron. They find

$$k = 1 - {\cdot}00048745t + {\cdot}00000010346t^2.$$

It will be noticed that their coefficient of t is greater than ours, our coefficient of t^2 greater than theirs. This may be partially accounted for by the fact that we carried our measurements to much higher temperatures than they. The rate of change of resistance with temperature decreases more rapidly at high than at low temperatures. We may here give a table of coefficients of the corresponding formulæ for iron and gold. A and B are the coefficients of t and t^2 respectively in the formula:

$$k \text{ or } r = 1 + At + Bt^2.$$

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* Phil. Trans. Roy. Soc. Lond., vol. cliv. (1864), p. 167.

Metal.	k or r.	A.	B.	Temperature Limits (C.).	Observer.
Iron,	k	$-{\cdot}00472$	$+{\cdot}0000084664$	0° – 244°	LENZ.[*]
„	r	$+{\cdot}004726$	0	low temps.	ED. BECQUEREL.[†]
„	r	$+{\cdot}0041304$	$+{\cdot}0000052713$	0° – 200°	ARNDTSEN.[‡]
„	k	$-{\cdot}0051182$	$+{\cdot}000012915$	10° – 100°	MATTHIESSEN and VOGT.[§]
„	r	$+{\cdot}004516$	$+{\cdot}000005828$	100° – 860°	BENOIT.[‖]
Gold,	k	$-{\cdot}0021341$	$+{\cdot}0000030684$	18° – 284°	LENZ.[¶]
„	r	$+{\cdot}003397$	0	low temps.	ED. BECQUEREL.[†]
„	k	$-{\cdot}0036745$	$+{\cdot}000008443$	10° – 100°	MATTHIESSEN and von BOSE.[**]
„	r	$+{\cdot}003678$	$+{\cdot}000000426$	100° – 860°	BENOIT.[‖]

It will thus be manifest that the rate of variation of the alloy's resistance with temperature for any ordinary temperature is not intermediate between those of its constituents, but is less than either of them. For

$$\frac{dk}{dt}\text{ for our alloy} = -{\cdot}00037198 + {\cdot}00001041 08t,$$

while according to MATTHIESSEN, VOGT and VON BOSE, whose temperature limits agree more closely with ours than the others',

$$\frac{dk}{dt}\text{ for iron} = -{\cdot}0051182 + .00002583t,$$

$$\frac{dk}{dt}\text{ for gold} = -{\cdot}0036745 + {\cdot}000016886t.$$

The above is true also, whichever of the values given in the table we regard as the most exact.[††]

Silver-Platinum Alloy.

Table II. gives the results of experiments with our only silver-platinum alloy. It contained 35 per cent. by mass or about 21·1 per cent. by volume of platinum.

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[*] Mem. de l'Acad. des Sci. de St. Petersbourg, t. ii. (1833), p. 652.

[†] Comptes Rendus, t. xxii. (1846), p. 416.

[‡] Pogg. Ann., Bd. civ. (1858), p. 1.

[§] Phil. Trans. Roy. Soc. Lond., vol. cliii. (1863), p. 373.

[‖] Comptes Rendus, t. lxxvi. (1873), p. 342. BENOIT has corrected his results for change of dimensions.

[¶] Mem. de l'Acad. des Sci. de St. Petersbourg, t. iii. pt. 1 (1838), p. 451.

[**] Phil. Trans., vol. clii. (1862), p. 23.

[††] See ARNDTSEN, Pogg. Ann., Bd. civ. (1858), p. 57.

TABLE II.

Temperature.	Resistance.	
	Observed.	Calculated.
16·0° C.	7·170	7·165
38·0	7·215	7·217
50·6	7·245	7·246
69·0	7·285	7·288
85·2	7·325	7·323
102·7	7·3575	7·360
118·7	7·395	7·392
135·4	7·425	7·425
151·3	7·455	7·455

These results may be combined in the formula:

$$R = 7{\cdot}126 + {\cdot}00248t - {\cdot}000002t^2,$$

whence

$$r = 1 + {\cdot}00034802t - {\cdot}00000028066t^2,$$

and

$$k = 1 - {\cdot}00034802t + {\cdot}00000040178t^2.$$

With this we may compare the formula which MATTHIESSEN and VOGT* give for an alloy of the same metals containing 19·65 per cent. by volume of platinum, viz.,

$$k = 1 - {\cdot}00033005t + {\cdot}00000020803t^2.$$

As in the former case, their formula applies only between 10°C and 100°C., and the discrepancy, though not great, may be partially due to this circumstance.

The following table contains the coefficients of corresponding formulæ for platinum and silver whose temperature limits are not very different from our own.

Metal.	k or r.	A.	B.	Temperature Limits (C.).	Observer.
Platinum,	k	− ·0027461	+ ·0000046494	0° − 233°	LENZ.
,,	r	+ ·0032724	0	0° − 200°	ARNDTSEN.
Silver,	k	− ·0036568	+ ·0000058993	0° − 213°	LENZ.
,,	r	+ ·0034142	0	0° − 200°	ARNDTSEN.
,,	k	− ·0038287	+ ·000009848	10° − 100°	MATTHIESSEN and von BOSE.

Again it is clear that the rate of variation of the resistance of the alloy is less than that of either of its constituents.

Silver-Palladium Alloys.

Table III. contains results of measurements of an alloy, 25 per cent. of which by mass and therefore about 23·6 per cent. by volume is palladium.

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* Phil. Trans. Roy. Soc. Lond., vol. cliv. (1864), p. 167.

TABLE III.

Temperature.	Resistance.	
	Observed.	Calculated.
16·5° C.	3·465	3·465
55·0	3·510	3·511
74·6	3·535	3·5345
95·2	3·555	3·5585
115·3	3·580	3·5816
135·4	3·605	3·6043
153·9	3·625	3·625

From these determinations we deduce the formula :

$$R = 3·44486 + ·001232t - ·0000004t^2,$$

whence

$$r = 1 + ·00035764t - ·00000011612t^2,$$

and

$$k = 1 - ·00035764t + ·00000024403t^2.$$

With the last we may compare MATTHIESSEN and VOGT's formula for an alloy of the same metals, 23·28 per cent. of whose volume is palladium :

$$k = 1 - ·00032391t + ·00000015421t^2.$$

BENOIT gives the following as the formula for palladium between 100° and 860° C.

$$r = 1 + ·002787t - ·000000611t^2.$$

Again therefore the alloy's rate of variation is less than that of either of its constituents.

Table IV. contains the measurements of another alloy of silver and palladium, 20 per cent. of which by mass and therefore about 18·85 per cent. by volume is palladium.

TABLE IV.

Temperature.	Resistance.	
	Observed.	Calculated.
15·5° C.	2·033	2·0314
32·2	2·047	2·0457
58·9	2·068	2·0679
71·0	2·078	2·0780
90·1	2·092	2·0934
110·5	2·112	2·1096
125·3	2·122	2·1211
136·5	2·129	2·1297
146·2	2·137	2·1370
156·4	2·144	2·1446

These measurements may be condensed in the following formula:

$$R = 2{\cdot}01797 + {\cdot}000875t - {\cdot}000000417t^2,$$

whence

$$r = 1 + {\cdot}00043361t - {\cdot}00000020665t^2,$$

and

$$k = 1 - {\cdot}00043361t + {\cdot}00000039467t^2.$$

It will be noticed that the resistances corresponding to the lowest three temperatures and calculated by the formula do not agree well with those observed. They are all somewhat less. If the temperature and resistance measurements be plotted so as to give a curve, it will be found to be very nearly a straight line at the lower temperatures. From about 70° C. downwards the rate of change of resistance is sensibly constant. We have thought it better, however, to use a formula of the same form as we have used for the other alloys, than to seek slightly greater accuracy in a new form.

Matthiessen and Vogt have studied no alloy whose composition is nearer this one's than that to which we have already referred.

The coefficient of t is in this case also less than the coefficient of t in the formula of either of the constituent metals.

Platinum-Iridium Alloys.

We have examined four platinum-iridium alloys. Table V. gives the observations on one containing 6 per cent. by mass, or about 6·57 per cent. by volume of iridium.

Table V.

Temperature.	Resistance.	
	Observed.	Calculated.
16·0° C.	14·945	14·876
40·0	15·351	15·351
61·8	15·72	15·761
80·5	16·095	16·095
100·5	16·465	16·435
119·8	16·75	16·745
155·2	17·245	17·270

From these numbers we deduce the formula,

$$R = 14{\cdot}543 + {\cdot}021125t - {\cdot}000022917t^2,$$

whence

$$r = 1 + {\cdot}0014526t - {\cdot}00000157584t^2,$$

and

$$k = 1 - {\cdot}0014526t + {\cdot}0000036859t^2.$$

Table VI. contains the results of observations on the alloy, 10 per cent. of which by mass or about 10·92 per cent. by volume is iridium.

TABLE VI.

Temperature.	Resistance.	
	Observed.	Calculated.
16·5° C.	2·747	2·7429
36·0	2·806	2·8036
57·8	2·875	2·8720
73·0	2·918	2·9196
95·3	2·987	2·9890
112·0	3·040	3·0398
124·7	3·080	3·0801
142·8	3·135	3·1360
155·6	3·175	3·1746

The following formula represents the above results.

$$R=2{\cdot}69+{\cdot}003165t-{\cdot}000000292t^2,$$

whence $$r=1+{\cdot}0011766t-{\cdot}00000010855t^2,$$

and $$k=1-{\cdot}0011766t+{\cdot}0000014929t^2.$$

Table VII. contains the measurements made with the alloy containing 15 per cent. by mass or about 16·29 per cent. by volume of iridium.

TABLE VII.

Temperature.	Resistance.	
	Observed.	Calculated.
24·8° C.	20·175	20·1651
50·6	20·560	20·5649
70·1	20·855	20·8657
85·2	21·103	21·0984
102·0	21·360	21·3571
118·0	21·594	21·6032
127·0	21·752	21·7416
140·6	21·950	21·9505
154·9	22·170	22·1700

The formula for this wire is:

$$R=19{\cdot}7817+{\cdot}015475t-{\cdot}000000417t^2,$$

whence $$r=1+{\cdot}00078229t-{\cdot}000000021063t^2,$$

and $$k=1-{\cdot}00078229t+{\cdot}00000063305t^2.$$

Table VIII. gives the measurements made with the fourth of these alloys, of which 20 per cent. by mass or about 21·61 per cent. by volume is iridium.

TABLE VIII.

Temperature.	Resistance.	
	Observed.	Calculated.
16·5° C.	5·756	5·7535
41·7	5·897	5·8998
60·0	6·000	6·0043
76·9	6·095	6·0996
94·7	6·197	6·1997
111·0	6·290	6·2883
129·7	6·393	6·3898
147·9	6·487	6·4871

This table gives the formula :

$$R = 5{\cdot}6563 + {\cdot}005925t - {\cdot}000002083t^2,$$

whence

$$r = 1 + {\cdot}0010475t - {\cdot}00000036832t^2,$$

and

$$k = 1 - {\cdot}0010475t - {\cdot}0000014156t^2.$$

With this last formula we may compare that given by MATTHIESSEN* for an alloy of the same metals 33·4 per cent. of which by mass was iridium, viz.,—

$$k = 1 - {\cdot}00064539t + {\cdot}00000059988t^2.$$

It agrees better with the formula of that alloy of ours which contains 15 per cent. of iridium than with that of the one containing 20 per cent.

If we compare the formulæ for the different platinum-iridium alloys, we find that in the case of those containing 6, 10, and 20 per cent. of iridium, there seems to be a general dependence of the values of the coefficients upon the constitution of the alloy. In the formula of the alloy containing most platinum, the coefficients both of t and t^2 have the greatest values. In that of the one which contains least platinum they are least, and for the intermediate alloy they have intermediate values. But neither our alloy containing 15 per cent. of iridium nor MATTHIESSEN'S containing $33\frac{1}{3}$ per cent. can take places in such a series. The relation is therefore probably only apparent. The groups of alloys which MATTHIESSEN and VOGT have examined show the same peculiarity, as may be seen by an inspection of their table.† Usually the rate of change of the resistance of the alloy increases with the percentage of one of the constituents, although exceptions are almost invariable.

In our observations on the thermo-electric properties of the same alloys of

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* Rep. of Brit. Ass. (1862), p. 137.

† Phil. Trans. Roy. Soc. Lond., vol. cliv. (1864), p. 167.

platinum and iridium as the above, we found that "at low temperatures, the greater the percentage of iridium, the higher is the line on the diagram;" but that "when we consider the position of the lines of other alloys of platinum and iridium determined by TAIT, the above simple relation between the constitution of the alloy and the position on the diagram, does not seem to hold."* It would thus appear that the thermo-electric properties of these alloys present peculiarities with reference to their chemical constitution similar to those of their electric conductivity.

We have given above the formula showing the relation which holds between the conductivity and temperature of platinum. It is scarcely necessary to point out that for these alloys, as well as those we have considered above, the rate of variation of resistance is less than the rate of variation of the resistance of the chief constituent. As no observer has yet determined this rate for iridium, the conclusion on this point cannot be so general as in the case of the other alloys.

For purposes of easy reference we give in Table IX. a synopsis of the above experiments. It contains the coefficients of the formulæ used above, which, stated generally, are:

$$r=1+at-bt^2,$$

and

$$k=1-at+ct^2,$$

as well as particulars as to the constitution of the alloys to which the coefficients refer.

TABLE IX.

Alloy.	Percentage Composition.		a.	b.	c.
	By Mass.	By Volume (about)			
Iron-Gold,	5 of Fe.	11·9 of Fe.	·00037198	·00000038217	·00000052054
Platinum-Silver,	35 of Pt.	21·1 of Pt.	·00034802	·00000028066	·00000040178
Palladium-Silver,	25 of Pd.	23·6 of Pd.	·00035764	·00000011612	·00000024403
,, ,,	20 of Pd.	18·85 of Pd.	·00043361	·00000020665	·00000039467
Platinum-Iridium,	6 of Ir.	6·57 of Ir.	·0014526	·00000157584	·0000036859
,, ,,	10 of Ir.	10·92 of Ir.	·0011766	·00000010855	·0000014929
,, ,,	15 of Ir.	16·29 of Ir.	·00078229	·000000021063	·00000063305
,, ,,	20 of Ir.	21·61 of Ir.	·0010475	·00000036832	·0000014156

The above experiments were performed in Prof. TAIT's Laboratory, University of Edinburgh, nearly three years ago. Their publication has been delayed because of the lack of an opportunity of working up the results.

Our thanks are due to Prof. TAIT, who furnished us both with the alloy wires themselves and the means of studying them.

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* See p. 335 of our paper cited above.

XXI.—*On the Differential Telephone.* By Professor CHRYSTAL.

(Revised 20th August 1880.)

PART I.

ON THE GENERAL THEORY OF THE INSTRUMENT, AND ON ITS APPLICATION TO ELECTRICAL MEASUREMENTS.

Some time before the telephone was invented, I had occasion to consider very closely the problem of the opposition offered to the passage of the electric current by an electrolyte, and to seek for new methods of dealing with it. It was not difficult to see that the telephone afforded advantages in this kind of electrical measurement. As far as regards the measurement of what is usually called Electrolytic *Polarisation,* these advantages are perhaps even greater than they might at first sight appear. In the case of what is generally called Electrolytic *Resistance,* they are, however, less than they appear.

As an instrument for use in resistance measurements, theory and practice lead me to believe that the telephone is far inferior to the galvanometer. I have found, however, that it can be used with great advantage in the measurement of coefficients of induction and of capacities.

The calculations in the earlier part of this paper were made more than two years ago; but it was not until this summer that I found leisure to bring them to the test of experiment. For an opportunity of so doing I am indebted to my colleague Professor TAIT, who has put the resources of his laboratory at my disposal. I am also much indebted to Sir WILLIAM THOMSON and Professor FLEEMING JENKIN for their kindness in lending me apparatus of different kinds.

In what follows, I select from a considerable number of theoretical investigations in my possession mainly those cases which I have tested by experiment.

The telephone indicates directly the variations of an electric current, and in this respect its function as a current detector is essentially different from all the ordinary electrical indicators. It is necessary, therefore, to work with a varying current. For some purposes, as I shall show later on, it would be essential to have a current subject to a simple harmonic variation of known frequency; but for most purposes, any kind of interrupted current will do, and since any periodic variation can be represented by a series of simple harmonic variations, I shall in all the theory that follows work with a single term of such a series.

There are two leading null methods in use for measuring resistances, with a galvanometer as indicator,—the differential galvanometer method and Wheatstone's bridge. I discuss the two corresponding methods for the telephone; but it is the former more especially to which I wish to direct attention.

The instrument which takes the place of the differential galvanometer, I call a differential telephone. It is simply an ordinary telephone wound double like a differential galvanometer. It is essential that this instrument shall stand the test of producing no sound when the same current is passed in opposite directions through its two coils. My first attempt to make such an instrument by winding the wires side by side in the ordinary way failed entirely. It was hopeless to attempt to compensate one coil, as is done in the case of a differential galvanometer; for it is obvious from the nature of the telephone that there must be null magnetic force all over the core, and throughout the ferrotype plate. I found, however, that the desired arrangement could be got by twisting up the wires of the telephone together, and then winding the twist upon the bobbin. The instruments with which I have worked are constructed in this way, and appear by every test I have applied to them to answer their purpose perfectly. At all events, any defect, if discovered, will certainly be so small as not to affect their use in practice. As an illustration of the completeness of the compensation and of the delicacy of the instrument, I may mention that when the current of three small Le Clanché cells, interrupted by a tuning fork, passes through the coils in opposite directions, nothing whatever can be heard, although one turn of the line wire outside the instrument restores the sound very distinctly, and the current through one coil produces a hum that can be heard a long way off.

One of the simplest applications of the differential telephone is to the comparison of coefficients of induction. In order to test this in practice, I fitted up the following rough arrangement which I mean to replace by a better, after I have settled by experience the most convenient disposition of the parts. $\alpha\beta$, $\gamma\delta$ are two pairs of coils mounted on two stems, so that they can be placed at any distances apart up to 30 cm. or so. AB, CD are the terminals of the two coils of the differential telephone, EK is a multiple arc in one branch of which are $\beta\alpha$, and AB, in the other $\delta\gamma$ and CD; the arrangement is such that the current passes in opposite directions round

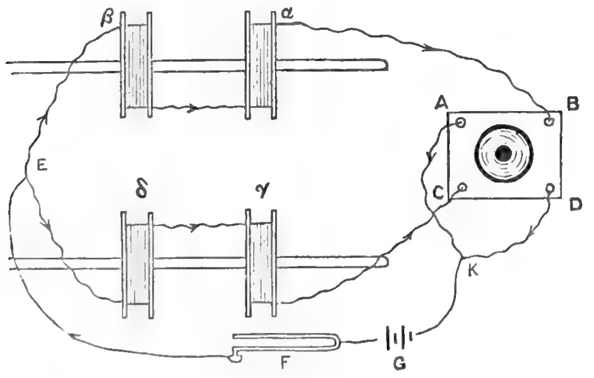


Fig. 1.

the core in AB and CD, so that when the currents are equal *at every instant* there is silence.

In the single part of the line there is a battery G, and an interruptor F, which was sometimes a microphone attached to a clock, sometimes a tuning fork, but oftenest a piece of watch spring attached to the pendulum of a small clock which grated over a milled head at the lowest part of each swing, and thus made a momentary contact. The last arrangement uses the least current, which is an advantage, but it also has the great virtue of being the most powerful noise-producer that I have been able to find.

The mathematical theory of the above arrangement, which is appended to this paper, shows that there can be silence in the differential telephone when, and only when, the resistances of both branches of the multiple arc are equal, and also their coefficients of self-induction. It is of no consequence what induction there is between the two branches.

When these two conditions are fulfilled there is silence for all frequencies, so that it is of no consequence what kind of interruptor we use.

There are thus two adjustments. If either of the two be not perfect, alteration of the other will produce a minimum of sound, but never absolute silence.

This is a simple instance of a principle in telephone measurements, the neglect of which has, I believe, hindered the success of many experimenters. They have tried to do that with one adjustment which could be done only with several. Hughes' induction balance, as used with the sonometer, is an instance in point; several instances of multiple adjustment are given below, and the general theory of the matter is discussed (see p. 615).

The mathematical expression for the square of the amplitude of the difference of the currents in the two coils, is a fraction whose denominator is essentially positive, and whose numerator is

$$4\pi^2 n^2 (\mathrm{M}-\mathrm{N})^2 + (\mathrm{Q}-\mathrm{R})^2;$$

where M and N are the coefficients of self-induction of the two branches, Q and R the resistances, and n is the frequency of the harmonic disturbance of the current. From this formula it is clear that the differential telephone is more sensitive to differences of coefficients of induction than to differences of resistances. Its proper use, therefore, is to compare induction coefficients, and not as a delicate resistance measurer.

In practice Q and R are first made equal by some of the ordinary methods, and then the equality of M and N is adjusted.

I have found that with 1000 ohms in each branch, the differential telephone is sensitive to differences of resistance up to about 1 per cent. only; whereas it is abundantly sensitive to the differences of the induction of the so-called inductionless coils of resistance boxes, *i.e.*, it can deal with induction coefficients of the order ·0001 earth quadrant.*

I propose to construct by means of the differential telephone, a scale of induction coefficients. This may be done as follows:—Suppose in fig. 1 that the two coils, β and δ, are fixed on the stems. Let v be a small coil of arbitrary induction coefficient v, and suppose χ to be another coil of the same resistance, but wound so as to have very little, say no, induction. α, the fellow coil to β, is placed so that there is no mutual induction between the pair; v is put in the branch along with these, and χ in the other branch. If the resistances were equal before, they will still be equal; then γ is placed on the stem and slid to a position x, where for which there is silence.

If N be the sum of the individual self-inductions of γ and δ (which is always the same), and ν_x double their coefficient of mutual induction when γ is at x, M the constant sum of the individual self-inductions of α and β, then we have

$$\mathrm{M}+v=\mathrm{N}+\nu_x .$$

v and χ are now removed, and α placed on the stem and slid along till there is a balance, a mark is made on the stem for this position and lettered 1.

Then

$$\begin{aligned}\mathrm{M}+\mu_1&=\mathrm{N}+\nu_x\\&=\mathrm{M}+v\,,\\\mu_1&=v\,.\end{aligned}$$

Now put v and χ in as before, and slide down γ until there is a balance; then take them out and slide down α till there is again a balance, and mark this position 2.

Then

$$\begin{aligned}\mathrm{M}+\mu_1+v&=\mathrm{N}+\nu_y\\&=\mathrm{N}+\mu_2\,,\\\mu_2-\mu_1&=v\,,\\\mu_2&=2v\,;\end{aligned}$$

and so on.

We thus graduate the stem into parts, each of which corresponds to an increase v of the self-induction of the circuit. Similarly we can graduate the other stem. It is then easy to interpolate and get a continuous scale. Lastly, we can, by a single observation, reading both stems, find the small difference M—N in terms of v.

---

* The self-induction coefficients of the primary and secondary of a middling-sized Ruhmkorff's coil, when expressed in the same unit, run to from ·01 to ·1, and from 50 to 100 respectively.

The instrument is now ready for measuring coefficients of self-induction that do not exceed twice the coefficient of mutual induction of either pair of coils when in close proximity.

We can now proceed by the process of continual doubling to make standards and prolong the scale beyond this limit. Thus we completely solve the problem of measuring coefficients of self-induction, and hence, of course, the problem of measuring induction coefficients generally. All that remains to be done is to get the absolute value of our arbitrary unit v.

Since the above was written, I have had an instrument constructed for giving varying self-induction with constant resistance. It is so devised as to give a scale of approximately constant sensibility, and at the same time to have a considerable range. I hope to be able soon to lay before the Society a description of this instrument, and of some results obtained with it.

Action of Neighbouring Circuits.

Another class of experiments of some interest may be made with the differential telephone.

If a conducting body, say a coin or a closed circuit of wire, be placed upon one of the pairs of coils, or, better still, between the members of one pair, the balance is disturbed. The sensitiveness of the instrument to influences of this kind is very great. A penny placed between the coils restores the sound very markedly, a half-crown still more so; in fact, a single circlet of thin copper wire of the diameter of one's middle finger, gives a sound which can be heard quite distinctly. These effects are analogous to those produced in HUGHES' instrument.

I append to this paper the mathematical theory of these experiments, from which it appears that a disturbance produced by a neighbouring circuit in one branch of the differential telephone cannot be compensated for all frequencies of the current variation, by merely adjusting the resistances and induction coefficients within the two branches. This is another instance of multiple adjustment.

The effect of a neighbouring circuit on one branch can be compensated by adjusting properly a neighbouring circuit to the other branch. If S and T denote the resistances, G and H the coefficients of self-induction, and I and J the coefficients of mutual induction with the respective branches, then the conditions for silence for all disturbances are

$$Q=R,\ M=N,\ SJ^2=TI^2,\ \frac{G}{S}=\frac{H}{T}.$$

The last of these conditions is that the time constants of the two neighbouring circuits must be equal, a condition which might easily have been foreseen. We shall have other instances of a similar condition.

There will be silence for a particular note whose frequency is $\frac{n}{2\pi}$, if

$$\lambda-n^2\nu=0\,,\qquad \mu-n^2\rho=0\,,$$

where

$$\begin{aligned}\lambda&=(Q-R)ST\,,\\ \mu&=(M-N)ST+(Q-R)(GT+HS)\,,\\ \nu&=(Q-R)GH+(M-N)(GT+HS)+SJ^2-TI^2\,,\\ \rho&=(M-N)GH+GJ^2-HI^2\,.\end{aligned}$$

A balance of this last kind would enable us to determine our arbitrary unit v in terms of a resistance, and hence to find its value in absolute C. G. S. units. For it will be observed that λ is of the third degree in resistance, while ν is of the first degree in resistance, and of the second in coefficients of induction; so that the first of the equations expresses a coefficient of induction in terms of n, and certain resistances, provided we can determine the ratios of the different coefficients, which we can do by means of the differential telephone itself, as we have seen.

This method would, however, require an instrument for producing a pure simple harmonic variation of electromotive force. As no apparatus of this kind is at present at my command, I have not attempted to test its practicability.

Comparison of Two Capacities.

To test the equality of the capacities of two condensers, we may proceed as follows:—

Let a balance be obtained with the two circuits of the differential telephone as usual, then select two parts of the circuit of equal resistance and equal self-induction; or, what comes to the same thing, introduce two equal resistances having equal self-induction, say two 1000 coils from a resistance box, one into each circuit, and attach the two condensers by thick wires whose resistance and self-induction are negligible, so as to include these identical parts of the two circuits between them. There will then be silence when, and only when, the capacities are equal.

From preliminary experiments, I believe that there will be no difficulty in comparing in this way capacities of the order of a microfarad to the $\frac{1}{1000000}$th part.

The application of this arrangement to the study of electrolytic polarisation is obvious, but I do not propose to enter on the matter here.

Comparison of Capacity with Self-Induction.

The following method allows us to measure capacity in terms of self-induction and resistance, or self-induction in terms of capacity and resistance:—

To make the principles involved clearer, I shall suppose that we can obtain resistances absolutely without self-induction (a method for applying correction for residual induction is given below).

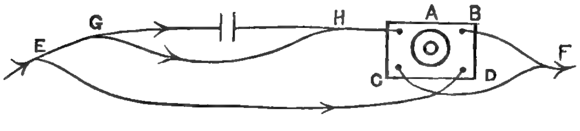


Fig. 2.

G H is a multiple arc, one branch contains a condenser of capacity X, and has resistance Q'', but no self-induction; the other branch has self-induction M', and resistance Q'. The self-induction and resistance of the rest of the circuit EABF are M and Q; the corresponding quantities for the other circuit EDCF are N and R. The necessary and sufficient conditions for silence *for all notes* are

$$Q''=Q', \qquad R=Q+Q',$$
$$M=N, \qquad XQ'=\frac{M'}{Q'}.$$

The last condition is simply that the time constant of the two branches of GH shall be equal; and we have the interesting result that a condenser and a coil can be so combined as to be equivalent *for all disturbances* to a simple resistance. The action of the two is reciprocal; at first the current passes entirely into the condenser, then more and more passes through the coil, and at last when the current is stationary (wholly or for the moment) it passes entirely through the coil. The one acts as a sort of spring or buffer to the other.

I believe that this method could be made most useful in practical testing, and that by means of a small coil with a movable iron core* empirically graduated, and a differential telephone capacity or self-induction could be measured with even greater ease than resistance.

General Theory.

The following general discussion of the theory of the induction currents in a system of linear conductors, in one branch of which there is a harmonically varying electromotive force, will help to bring out the fundamental principles which underlie all the applications that follow. These priciples I believe furnish the key to the theory of the telephone, in so far as it is purely electrical; and it is on them that we must proceed in forming null methods of electrical measurement in which the telephone is to be used.

Let $x_1, x_2, \ldots\ldots x_r$ denote the current strengths at time t in the different circuits, and $A \sin nt$ the varying external electromotive force in the first circuit, there being no external electromotive force in any other circuit; then x_1, x_2,

---

* Strictly speaking, an iron core is inadmissible in measurements with the telephone, because it acts as a neighbouring circuit, and introduces disturbances that cannot be compensated in a simple manner. I have found, however, in practice that, when the core is made of thin wires well insulated from one another, these residual effects are so small as not to interfere with the results, where the utmost nicety is not required.

. . . . . . x_r, satisfy a system of linear differential equations with constant coefficients and certain equations of continuity.*

Elimination from these equations gives for the current in any branch

$$\begin{aligned}&(a_0+a_1\mathrm{D}+a_2\mathrm{D}^2\ldots\ldots+a_p\mathrm{D}^p)x\\ &=\mathrm{A}(\lambda_0+\lambda_1\mathrm{D}+\ldots\ldots+\lambda_q\mathrm{D}^q)\sin nt \quad . \quad . \quad . \quad . \qquad (1)\end{aligned}$$

where D stands for $\frac{d}{dt}$, and the a's and λ's are functions of the coefficients of induction, resistances, and capacities of the circuits.

Hence

$$x=\mathrm{A}\frac{(\lambda_0+\lambda_1\mathrm{D}+\ldots\ldots+\lambda_q\mathrm{D}^q)(a_0-a_1\mathrm{D}+a_2\mathrm{D}^2-\ldots\ldots)}{(a_0+a_2\mathrm{D}^2+a_4\mathrm{D}^4+\ldots\ldots)^2-(a_1+a_3\mathrm{D}^2+\ldots\ldots)^2\mathrm{D}^2}\sin nt\,,$$

$$\begin{aligned}=\frac{1}{\text{etc.}}\Big\{&\{(\lambda_0-\lambda_2n^2+\ldots\ldots)(a_0-a_2n^2+\ldots\ldots)+(\lambda_1-\lambda_3n^2+\ldots\ldots)(a_1-a_3n^2+\ldots\ldots)n^2\}\sin nt\\ &+\{-(\lambda_0-\lambda_2n^2+\ldots\ldots)(a_1-a_3n^2+\ldots\ldots)n+(\lambda_1-\lambda_3n^2+\ldots\ldots)(a_0-a_2n^2+\ldots\ldots)n\}\cos nt\Big\}, \qquad (2)\end{aligned}$$

whence

$$x=\left\{\frac{(\lambda_0-\lambda_2n^2+\ldots\ldots)^2+n^2(\lambda_1-\lambda_3n^2+\ldots\ldots)^2}{(a_0-a_2n^2+\ldots\ldots)^2+n^2(a_1-a_3n^2+\ldots\ldots)^2}\right\}^{\frac{1}{2}}\sin(nt+\epsilon) \quad . \quad . \qquad (3)$$

In (2) and (3) the letters a are the same for all the x's, but the λ's are different for different x's. Hence the expression for the difference of two x's, say x_r-x_s, takes the *same form* as the expression (3), the place of λ_0, λ_1, &c., being taken by the differences of the corresponding coefficients for x_r and x_s.

The condition therefore that the current in any branch shall be zero, or the conditions that the currents in two assigned branches shall be equal, take the form

$$\left.\begin{aligned}\lambda_0-\lambda_2n^2+\lambda^4n^4-\ldots\ldots=0\\ \lambda_1-\lambda_3n^2+\lambda_5n^4-\ldots\ldots=0\end{aligned}\right\} \quad . \quad . \quad . \quad . \qquad (4)$$

For a given frequency of the simple harmonic variation, therefore, two conditions are in general necessary and sufficient to secure either that the current in any one branch of the system shall be zero, or that the currents in two named branches shall be equal.

If this is to be the case for all frequencies, then all the λ's must vanish; and q conditions must in general be satisfied. It is in general impossible, therefore, to get an absolute null method depending on one adjustment only, when the telephone is used as an indicator.

---

* It would be easy to work out the general theory with more detail, much in the way that a system of conductors is treated when induction is neglected. (See MAXWELL's "Electricity and Magnetism," or article "Electricity," Encyclopædia Britannica, vol. viii. p. 43).

Differential Telephone, with a Neighbouring Circuit to each Branch.

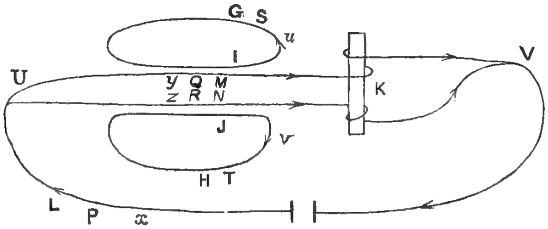


Fig. 3.

Let the current, resistance, and coefficient of self-induction be denoted as follows :—

For the line, ...	x, P, L ;
,, 1st branch of differential telephone, .	y, Q, M ;
,, 2d do.	z, R, N ;
,, 1st neighbouring circuit, . . .	u, S, G ;
,, 2d do.	v, T, H .

Farther, let the coefficients of mutual induction of the two neighbouring circuits, each with its corresponding branch, be I and J; and that of the coils of the differential telephone K.

If U and V be the potentials, at any time t at the two points UV, then we have

$$(\mathrm{LD}+\mathrm{P})x=\mathrm{A}\sin nt+\mathrm{V}-\mathrm{U} \quad . \quad . \quad . \quad . \quad (1)$$

$$(\mathrm{MD}+\mathrm{Q})y-\mathrm{KD}z+\mathrm{ID}u=\mathrm{U}-\mathrm{V} \quad . \quad . \quad . \quad . \quad (2)$$

$$-\mathrm{KD}y+(\mathrm{ND}+\mathrm{R})z+\mathrm{JD}v=\mathrm{U}-\mathrm{V} \quad . \quad . \quad . \quad (3)$$

$$(\mathrm{GD}+\mathrm{S})u+\mathrm{ID}y=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$(\mathrm{HD}+\mathrm{T})v+\mathrm{JD}z=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$x=y+z \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Here D is used for shortness instead of $\frac{d}{dt}$. We may at once replace (1), (2), (3), and (6) by the following :—

$$\{(\mathrm{L}+\mathrm{M})\mathrm{D}+\mathrm{P}+\mathrm{Q}\}y+\{(\mathrm{L}-\mathrm{K})\mathrm{D}+\mathrm{P}\}z+\mathrm{ID}u=\mathrm{A}\sin nt \quad . \quad (7)$$

$$\{(\mathrm{L}-\mathrm{K})\mathrm{D}+\mathrm{P}\}y+\{(\mathrm{L}+\mathrm{N})\mathrm{D}+\mathrm{P}+\mathrm{R}\}z+\mathrm{JD}v=\mathrm{A}\sin nt \quad . \quad (8)$$

There is no difficulty in finding y and z by means of (4), (5), (7), and (8); but the expressions are complicated, and I avoid them here.

For silence we must have $y=z$. We can express the mathematical conditions for this equality without solving the equations. We get, in fact,

$$\left\{(2\mathrm{L}+\mathrm{M}-\mathrm{K})\mathrm{D}+2\mathrm{P}+\mathrm{Q}-\frac{\mathrm{I}^2\mathrm{D}^2}{\mathrm{GD}+\mathrm{S}}\right\}y=\mathrm{A}\sin nt\,,$$

$$\left\{(2\mathrm{L}+\mathrm{N}-\mathrm{K})\mathrm{D}+2\mathrm{P}+\mathrm{R}-\frac{\mathrm{J}^2\mathrm{D}^2}{\mathrm{HD}+\mathrm{T}}\right\}y=\mathrm{A}\sin nt\,.$$

Hence we must have

$$(\lambda+\mu\mathrm{D}+\nu\mathrm{D}^2+\rho\mathrm{D}^3)\sin nt=0 \quad . \quad . \quad . \quad . \quad (9)$$

where

$$\begin{aligned}
\lambda&=(\mathrm{Q}-\mathrm{R})\mathrm{ST}\,,\\
\mu&=(\mathrm{M}-\mathrm{N})\mathrm{ST}+(\mathrm{Q}-\mathrm{R})(\mathrm{GT}+\mathrm{HS})\,,\\
\nu&=(\mathrm{Q}-\mathrm{R})\mathrm{GH}+(\mathrm{M}-\mathrm{N})(\mathrm{GT}+\mathrm{HS})+\mathrm{SJ}^2-\mathrm{TI}^2\,,\\
\rho&=(\mathrm{M}-\mathrm{N})\mathrm{GH}+\mathrm{GJ}^2-\mathrm{HI}^2\,.
\end{aligned}$$

Hence the conditions for silence are

$$\left.\begin{aligned}\lambda-n^2\nu=0\\ \mu-n^2\rho=0\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

If there is to be silence for all frequencies, then we must have

$$\lambda=0\,,\ \mu=0\,,\ \nu=0\,,\ \rho=0\,,$$

which require

$$\begin{aligned}
\mathrm{Q}&=\mathrm{R}\,,\\
\mathrm{M}&=\mathrm{N}\,,\\
\mathrm{SJ}^2&=\mathrm{TI}^2\,,\\
\mathrm{GJ}^2&=\mathrm{HI}^2\,.
\end{aligned}$$

Case of one Neighbouring Circuit.—If we make $\mathrm{T}=\infty$, the conditions (10) become

$$\lambda-n^2\nu=0\,,\ \mu=0 \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where

$$\lambda=(\mathrm{Q}-\mathrm{R})\mathrm{S}\,,\ \mu=(\mathrm{M}-\mathrm{N})\mathrm{S}+(\mathrm{Q}-\mathrm{R})\mathrm{G}\,,\ \nu=(\mathrm{M}-\mathrm{N})\mathrm{G}-\mathrm{I}^2\,.$$

From these formulæ we see that silence may be obtained for given frequency, but silence for all frequencies is impossible.

Case of no Neighbouring Circuits.—The conditions reduce to

$$\mathrm{M}-\mathrm{N}=0\,,\ \mathrm{Q}-\mathrm{R}=0\,,$$

as may be seen by putting $S=\infty$ and $T=\infty$. In this case there is absolute silence. The expression for the maximum value of $y-z$ is

$$A\sqrt{\frac{n^2(M-N)^2+(Q-R)^2}{(\psi-n^2\phi)^2+n^2\chi^2}},$$

where

$$\phi=MN+NL+LM+2KL-K^2,$$

$$\chi=P(M+N)+Q(N+L)+R(L+M)+2KP,$$

$$\psi=QR+RP+PQ.$$

On account of their complexity I refrain from giving the corresponding formulæ in the general case, but they can be obtained without difficulty.

Comparison of Capacities.

Suppose the two circuits of the differential telephone to branch into multiple arcs AB and CD, and in one of the branches of each of these multiple arcs let there be condensers of capacities X and Y respectively. Let the current strengths at any moment in these branches be y'' and z'', and suppose for the present that the wires in these branches are short and thick, so that their resistance and self-induction may be neglected. Let the current strength, resistance, and coefficient of self-induction of the other branches of AB and CD be y', Q', M', z', R', N' respectively, and the corresponding quantities for the rest of the two circuits of the telephone y, Q, M, and z, R, N respectively. Then A, B, &c., denoting the potentials at the respective points, and $\dot{A}$, $\dot{B}$, &c., their differential coefficients with respect to the time, we have the following equations :—

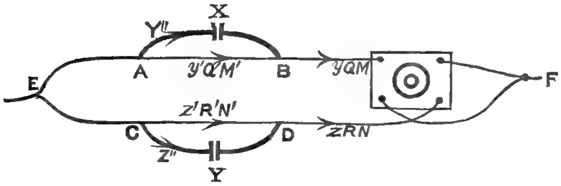


Fig. 4.

$$(M'D^2+Q'D)y'=\dot{A}-\dot{B}=\frac{1}{X}y'' \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$(N'D^2+R'D)z'=\dot{C}-\dot{D}=\frac{1}{Y}z'' \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$(MD^2+QD)y-KD^2z=E-\dot{F}-(\dot{A}-\dot{B}) \quad . \quad . \quad . \quad (3)$$

$$(ND^2+RD)z-KD^2y=\dot{E}-\dot{F}-(\dot{C}-\dot{D}) \quad . \quad . \quad . \quad (4)$$

$$y=y'+y'' \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$z=z'+z'' \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

From these equations we get

$$\left\{\mathrm{MD}^2+\mathrm{QD}+\frac{(\mathrm{M'D}^2+\mathrm{Q'D})\frac{1}{\mathrm{X}}}{\mathrm{M'D}^2+\mathrm{Q'D}+\frac{1}{\mathrm{X}}}\right\}y-\mathrm{KD}^2z=\dot{\mathrm{E}}-\dot{\mathrm{F}}\,,$$

$$\left\{\mathrm{ND}^2+\mathrm{RD}+\frac{(\mathrm{N'D}^2+\mathrm{K'D})\frac{1}{\mathrm{Y}}}{\mathrm{N'D}^2+\mathrm{R'D}+\frac{1}{\mathrm{Y}}}\right\}z-\mathrm{KD}^2y=\dot{\mathrm{E}}-\dot{\mathrm{F}}\,.$$

The condition $y=z$ gives

$$\{(\mathrm{M}-\mathrm{N})\mathrm{D}+(\mathrm{Q}-\mathrm{R})\}\left\{\mathrm{M'D}^2+\mathrm{Q'D}+\frac{1}{\mathrm{X}}\right\}\left\{\mathrm{N'D}^2+\mathrm{R'D}+\frac{1}{\mathrm{Y}}\right\}$$

$$+\frac{1}{\mathrm{X}}\left\{\mathrm{M'D}+\mathrm{Q'}\right\}\left\{\mathrm{N'D}^2+\mathrm{R'D}+\frac{1}{\mathrm{Y}}\right\}-\frac{1}{\mathrm{Y}}\left\{\mathrm{N'D}+\mathrm{R'}\right\}\left\{\mathrm{M'D}^2+\mathrm{Q'D}+\frac{1}{\mathrm{X}}\right\}=\mathrm{Q}\,.$$

Equating to zero coefficients of D, we get

$$\mathrm{M}-\mathrm{N}=0\,,\qquad \mathrm{Q}-\mathrm{R}=0\,,$$

$$\mathrm{M'N'}\left(\frac{1}{\mathrm{X}}-\frac{1}{\mathrm{Y}}\right)=0\,,$$

$$(\mathrm{M'R'}+\mathrm{W'Q'})\left(\frac{1}{\mathrm{X}}-\frac{1}{\mathrm{Y}}\right)=0\,,$$

$$(\mathrm{M'}-\mathrm{N'})\frac{1}{\mathrm{XY}}+\mathrm{Q'R'}\left(\frac{1}{\mathrm{X}}-\frac{1}{\mathrm{Y}}\right)=0\,,$$

$$(\mathrm{Q'}-\mathrm{R'})\frac{1}{\mathrm{XY}}=0\,,$$

The last four equations require that

$$\mathrm{X}=\mathrm{Y}\,,\ \mathrm{M'}=\mathrm{N'}\,,\ \mathrm{Q'}=\mathrm{R'}\,.$$

And conversely, if we attach a condenser by means of very thick electrodes to one circuit of a differential telephone, and attempt to balance it by attaching similarly a condenser to the other circuit, the capacities of the condensers must be equal, the resistance and self-induction included between the armatures must be the same on both sides, and the resistance and self-induction of the remainder of each circuit must be the same. Here, therefore, five independent adjustments are necessary to secure silence in the differential telephone for all frequencies of the varying electromotive force.

Comparison of Capacity with Coefficient of Induction.

In last case (fig. 4) let us suppose the branch of AB, which contains the condenser, to be removed, and let R and N now stand for the resistance and self-induction of the whole of one circuit of the differential telephone. Farther, let us suppose that the condenser branch of AB has resistance Q″, and self-induction M″.

The equations of the systems now become

$$(M'D^2+Q'D)y'=\dot{A}-\dot{B}=\left(M''D^2+Q''D+\frac{1}{X}\right)y'', \quad . \quad . \quad (1)$$

$$(MD^2+QD)y=\dot{E}-\dot{F}-(\dot{A}-\dot{B}) , \quad . \quad . \quad . \quad . \quad (2)$$

$$(ND^2+RD)z=\dot{E}-\dot{F} , \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$y=y'+y'' , \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The condition $y=z$ gives

$$(\lambda+\mu D+\nu D^2+\rho D^3)y=0 , \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where $\lambda=\frac{Q'+Q-R}{X}$,

$$\mu=\frac{M'}{X}+Q'Q''+(Q'+Q'')(Q-R)+\frac{M-N}{X} ,$$

$$\nu=Q'M''+Q''M'+(Q-R)(M'+M'')+(Q'+Q'')(M-N) ,$$

$$\rho=(M'+M'')(M-N)+M'M'' .$$

The condition for *absolute* silence is that these four expressions shall all vanish. Using the first of these conditions to modify the second and third, we may write the four

$$R=Q+Q' , \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$M'(Q''-Q')+(Q'+Q'')(M-N)=0 , \quad . \quad . \quad . \quad . \quad (7)$$

$$\frac{M'+M-N}{X}=Q'^2 , \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$N=M+\frac{M'M''}{M'+M''} , \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Let us first take the ideal case where $M''=0$; the conditions then reduce to

$$R=Q+Q' , \ Q''=Q' , \ M'=Q'^2X , \ M=N .$$

This case is only approximately realisable in practice, because the self-induction of the so-called inductionless resistance coils, is quite sensible when tested by so delicate an instrument as the differential telephone. Along with any resistance Q'' we must always introduce a certain residual self-induction M''.

The general formulæ (6), (7), (8), and (9), enable us to correct our experimental results. The following may be conveniently used in place (7), (8), (9), to which they are equivalent,

$$M''=\frac{Q''-Q'}{2Q}M' , \qquad \text{(I.)}$$

$$N-M=-\frac{Q''-Q'}{Q''+Q'}M' , \qquad \text{(II.)}$$

$$M'=\frac{Q'(Q'+Q'')}{2}X , \qquad \text{(III.)}$$

In practice, however, we may in most cases proceed as follows. Since M'' is very small compared with M', (9) gives approximately $N=M+M''$.

N and M are adjusted accordingly. Then either X or M' is adjusted, taking Q'' always $=Q'$, until there is approximate silence. Lastly, Q'' is increased concurrently with residual adjustment of M' or X, as the case may be, until absolute silence is obtained.

CASE OF MULTIPLE ARC WITH INDUCTION.

It will be noticed that by equation (9) the coefficients of induction in the multiple arc are combined like resistances. An interesting case, which brings this out still better, is that where we have in one circuit of the differential telephone a multiple arc, each branch of which has induction. This case is obtained from last by putting $X=\infty$ in the conditions derived from (5). We thus get

$$R=Q+\frac{Q'Q''}{Q'+Q''} ,$$

$$Q'M''+Q''M'+(Q-R)(M'+M'')+(Q'+Q'')(M-N)=0,$$

$$N=M+\frac{M'M''}{M'+M''} \cdot$$

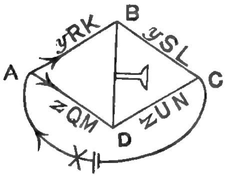
Using the first and last, the second of these gives

$$\frac{M'}{Q'}=\frac{M''}{Q''} \cdot$$

In other words, the time constants of the two branches of the multiple arc must be equal, and the resistances and coefficients of induction of the two circuits of the telephone must be equal, the inductions being combined by the same law as the resistances.

WHEATSTONE'S BRIDGE.

As an example of the application of the foregoing theory to Wheatstone's bridge, consider the case where all the arms have self-induction and two opposite arms have mutual induction.



Let the current, resistance, and self-induction in the branches of the bridge be y,R,K, y,S,L, &c., the current in the circuit BD in which the telephone is inserted being supposed zero; and let the coefficient of mutual induction of AB and DC be X. We have, since B=D, in order that there may be silence in the telephone,

$$(\mathrm{KD}+\mathrm{R})y+\mathrm{XD}z=\dot{\mathrm{A}}-\dot{\mathrm{B}}=\dot{\mathrm{A}}-\dot{\mathrm{D}}=(\mathrm{MD}+\mathrm{T})z \quad . \quad . \quad (1)$$

$$(\mathrm{LD}+\mathrm{S})y=\dot{\mathrm{B}}-\dot{\mathrm{C}}=\dot{\mathrm{D}}-\dot{\mathrm{C}}=(\mathrm{ND}+\mathrm{U})z+\mathrm{XD}y \quad . \quad . \quad (2)$$

Hence

$$(\mathrm{KD}+\mathrm{R})y=\{(\mathrm{M}+\mathrm{X})\mathrm{D}+\mathrm{T}\}z\,,$$

$$\{(\mathrm{L}-\mathrm{X})\mathrm{D}+\mathrm{S}\}y=(\mathrm{ND}+\mathrm{U})z\,,$$

which gives

$$[\{(\mathrm{L}-\mathrm{X})\mathrm{D}+\mathrm{S}\}\{(\mathrm{M}-\mathrm{X})\mathrm{D}+\mathrm{T}\}-(\mathrm{KD}+\mathrm{R})(\mathrm{ND}+\mathrm{U})]\sin nt=0 \quad . \quad (3)$$

The conditions for silence are therefore

$$\left.\begin{aligned}\lambda-\nu n^2&=0\,,\\ \mu&=0\,,\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where

$$\left.\begin{aligned}\lambda&=\mathrm{ST}-\mathrm{RU}\,,\\ \mu&=\mathrm{LT}+\mathrm{MS}-\mathrm{KU}-\mathrm{NR}-(\mathrm{S}+\mathrm{T})\mathrm{X}\,,\\ \nu&=\mathrm{LM}-\mathrm{KN}-(\mathrm{L}+\mathrm{M})\mathrm{X}+\mathrm{X}^2\,,\end{aligned}\right\} \quad . \quad . \quad (5)$$

For absolute silence we must have

$$\lambda=0\,,\ \mu=0\,,\ \nu=0\,. \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Comparison of two Coefficients of Self-Induction.—If M=0, N=0, X=0, (6) reduce to

$$\mathrm{ST}-\mathrm{RU}=0\,,\ \mathrm{LT}-\mathrm{KU}=0\,.$$

This case is given by MAXWELL, "Electricity and Magnetism," vol. ii. p. 357.

Comparison of Coefficients of Mutual with Coefficients of Self-Induction.—If L=0, M=0, (6) reduce to

$$\mathrm{ST}-\mathrm{RU}=0\,,\ \mathrm{X}=-\frac{\mathrm{KU}+\mathrm{NR}}{\mathrm{S}+\mathrm{T}}\,,\ \mathrm{X}^2=\mathrm{KN}\,.$$

If the mutual induction be between the adjacent branches AB and BC, and if $M=0$, $N=0$, the conditions for absolute silence reduce to

$$ST-RU=0\,,\ X=\frac{LT-KU}{U-T}\,.$$

Comparison of two Capacities.—If we attach condensers of capacities X and Y respectively by short thick wires to BC and DC, the conditions for absolute silence will be

$$ST-RU=0\,,\ RX-TY=0\,,$$

provided the self-inductions of all the four arms of the bridge be negligible.

Comparison of a Capacity with a Coefficient of Self-Induction.—If a condenser of capacity X be attached to B and C, and if the resistance of its attachments be S′, their self-induction being negligible, and if $K=0$, $M=0$, $N=0$, then the conditions for absolute silence are

$$ST-RU=0\,,\ S'=S\,,\ XS^2=L\,.$$

This is the equivalent of one of the methods given above for the differential telephone.

We may also suppose $S'=0$, $K=0$, $L=0$, $N=0$; the conditions for absolute silence are then

$$ST-RU=0\,,\ XST=M\,.$$

This arrangement is described by MAXWELL, "Electricity and Magnetism," vol. ii. p. 377.

All these arrangements are more or less troublesome on account of the imperfection of the correction for induction in ordinary resistance boxes. This comes out very remarkably when attempts are made (as some have suggested) to employ the telephone instead of a galvanometer in measuring resistances with Wheatstone's bridge. At what the galvanometer indicates as a balance even with nothing but coils from resistance boxes in the arms, the telephone sounds loudly, and alterations of the resistance up to one per cent. affect the sound but little. We are measuring, in fact, the inequalities of the coefficients of self-induction of the resistance coils.

Added during printing.—There is yet another source of disturbance which will undoubtedly make itself felt in some cases, viz., the electrostatic capacity of the coils used for resistance or induction standards. I reserve the mathematical discussion of this correction until experiment has settled in what cases it will be of practical importance. It is scarcely necessary to point out that disturbances of this kind are not a peculiar feature in telephonic measurements; they appear equally in the older methods of dealing with electromagnetic induction.

PART II.

On certain Experiments, mainly with the Differential Telephone.

The following experiments appear to me to be of interest, because they show that the theory of the telephone, in so far as it is purely electrical, comes well under recognised principles. In saying this I do not mean to prejudice the important acoustical questions that are as yet unsettled, or the difficult question as to the exact role of the magnetism of the core.

I shall assume that there is a disturbing electromotive force, which is a simple harmonic function of the time, so that under all circumstances the current in the telephone circuit will also be a simple harmonic function of the time, of the same period, but in general of different phase. Representing the harmonic disturbance of the electromotive force by $A \sin nt$, I shall suppose in all that follows that A is independent of n. This corresponds *practically* with the case of a microphone-sender, where the variation is really in the resistance however.[*] In the case of the telephone-sender, or a sine-inductor, A is proportional to n, within certain limits. Neither of these laws, of course, is exact, for it must be remembered that magnetisation lags behind magnetising force,[†] so that in all probability the amount of magnetism developed by rapidly alternating forces gets less and less as the frequency increases. In the case of a telephone-sender and a telephone-receiver this tells twice over.

I shall further assume that, for a given bobbin, core, and vibrating plate, the intensity of the sound is proportional to the square of the amplitude of the harmonic variation of the current in the receiving telephone. In the case of the differential telephone, the two coils of which may be regarded as exactly alike, and similarly placed with regard to the core and plate, the square of the amplitude of the algebraic sum of the currents is taken.

It is needless to discuss the physical grounds for the above assumptions, for in all that follows the question is one merely of greater and less. Besides, the experimental basis for such a discussion is wanting, inasmuch as there is, so far as I am aware, no definite idea among physicists as to how the ear compares the intensities of notes of different pitch.

Experiment 1.—If we use the differential telephone as a receiver, we may arrange it three different ways:—I. with only one coil in the circuit, the other being open; II. with two coils in series (aiding each other, of course); III. with the two coils in circuit abreast, so as to form a multiple arc.

Under all circumstances, the sound is louder with III. than with I., but in

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[*] See Aron, Wied. Ann. N.F., vi. p. 403.

[†] On this subject see two very interesting articles by Lord Rayleigh, Phil. Mag., 1869, p. 8, and ser. 5, vol. iii. p. 46 (1877).

passing from I. to III. the lower tones are more intensified than the higher. When the resistance (R) of the sender and line is small compared with (S), that of one of the coils of the receiver, this effect is very remarkable. If the current be interrupted by rasping the wire on a file, the effect of III. compared with I. is most curious from the deep croaking character which the sound assumes.

When the resistance and self-induction of the sender and line are small, the sound is louder with III. than with II.; but if either one or other of these be large enough, the result is the other way.

Again, if the resistance and self-induction of the line and sender be small, I. is better than II.; but if the self-induction of the line be above a certain limit, II. is better than I. for all tones; and if the resistance of the line be above a certain limit, and its self-induction not too great, then I. will be better than II. for some tones, and worse for others.

Experiment 2.—An ordinary Bell telephone was placed mouth downwards on a box on which a clock was ticking, and another telephone used as a receiver. When the secondary of a small induction coil with a core, the primary being open, was inserted in the line the sound became inaudible. It was found, however, that it could be restored by connecting a condenser of a certain capacity in multiple arc with the secondary coil, the (inductionless) resistance in the condenser branch being equal to that of the coil.

This is in accordance with what has been shown above, viz., that an arc of two branches of equal resistance Q, one having no capacity but induction L, the other no induction but a capacity X, is equivalent for all disturbances to a resistance Q without induction or capacity, provided $XQ^2=L$.

Experiment 3.—It was found that under certain circumstances sounds could be heard better with a condenser in the line than through a line of the same resistance and self-induction without a condenser. In other words, self-induction can be compensated by introducing capacity. I mean to return at some future time to this experiment, from which I hope to get some important results. I may simply mention that the result is quite in accordance with theory.* A similar case is that studied by KOHLRAUSCH (see article Electricity, "Encyclopædia Britannica," vol. viii. p. 49), in his investigations on electrolytic resistance.

Experiment 4.—One coil of the differential telephone was used as a receiver; the sender was an apparatus at a distance for making a momentary rasping contact. In point of fact, a small piece of watch spring attached to a clock pendulum and rasping on a milled head was frequently used, at other times a microphone. Two or three Le Clanché cells furnished the electromotive force. Sometimes a Bell telephone was used as a sender, and then the

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* The compensation according to theory is exact for one particular note only.

discontinuous contact and the battery were absent. The results were in all cases much the same, allowance, of course, being made for the difference of the general character of the sounds.

It was found, under the above circumstances, that the sound was greatly weakened when the second coil of the differential telephone was closed. Thus, when the sound was so loud that it could be heard all over the room, closing the second coil deadened it so much that it could scarcely be heard at a distance at all.

Not only is the intensity very much affected, but the *quality* of the sound is greatly altered. The high tones are much more deadened than the low, consequently the sound is deepened in character.

The deadening effect was found, as might be expected, to decrease when the second coil was closed through a greater and greater (inductionless) resistance.

Experiment 5.—The arrangements being as before, it was found that closing the second coil of the differential telephone through a resistance of 9 ohms with a considerable self-induction (coefficient$=\cdot016$ earth-quad. or thereby) has less deadening effect than closing it through 9 ohms taken from a resistance box, and therefore having very little self-induction.

Experiment 6.—The effect of closing the coil through a condenser was as follows:—When the capacity is very small, the deadening effect is, of course, nil; and when it is very great, the result is the same as if the condenser were short circuited. It was found that in certain cases, for a given tone, closing the neighbouring coil through a certain capacity *increased* the sound, so that there was a certain capacity for which the sound was best heard, and better heard than when the second coil was open, and therefore idle.

This experiment succeeds very well when a very faint sound is used, say a tick sent by a Bell telephone so as to be scarcely audible when the second coil of the receiving differential telephone is open; under these circumstances, the increase of the sound by closing the second coil through a condenser of proper capacity is very marked.

Experiment 7.—This is a repetition of GRANT's experiment* under more favourable circumstances. The sending instrument was either a microphone or a rasping contact. The secondary coil (resistance 44 ohms, coefficient of self-induction ·2 earth-quad.) of a small induction coil, with a bundle of covered iron wires for a core, was inserted in the line, and the receiver was one coil of the differential telephone so often alluded to above (the second coil was left open). This arrangement I shall call I.; when the primary (res. ·3 ohm, self-ind. ·004) was closed simply, we have arrangement II.; when the primary was closed through a condenser, arrangement III.

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* Phil. Mag., May 1880.

In passing from I. to II. the intensity of all the tones of a composite sound are markedly increased ; but the increase is greater for the high tones, so that the quality is somewhat raised.

When the capacity is very small, it is obvious beforehand that I. and III. would coincide, and when it is very large, II. and III. would be identical. For intermediate capacities the effects are as follows :—For a certain capacity, in passing from I. to III., the high tones alone are increased in loudness, so that there is a rather marked raising of the quality; still on passing from II. to III., there is rather a lowering of the quality. When the capacity is greater, the sharpening effect is much greater, and, on account of contrast between high tones and low tones, it is more striking in passing from II. to III. than in passing from I. to III. When the capacity is still farther increased, it becomes difficult to distinguish between II. and III.

Experiment 8.—These results were much more marked when the primary coil was closed through the second coil of the differential telephone. On introducing a condenser with this arrangement the sound passed from a *croak, croak,* to a loud sharp *tsit, tsit.*[*]

THEORY OF THE FOREGOING EXPERIMENTS.

Experiment 1.—Denoting by ξ_1, ξ_2, ξ_3 the relative intensities (measured as above explained) in arrangements I., II., and III. of a note of frequency $\frac{n}{2\pi}$, we get easily

$$\xi_1=\frac{1}{(L+N)^2n^2+(R+S)^2},$$

$$\xi_2=\frac{4}{(L+4N)^2n^2+(R+2S)^2},$$

$$\xi_3=\frac{1}{(L+N)^2n^2+\left(R+\frac{S}{2}\right)^2}.$$

Where L and R denote the coefficient of self-induction of the line and sender, N and S the self-induction and resistance of either coil of the differential telephone; the coefficient of mutual induction between the two coils is taken to be N.

It is obvious at once that under all circumstances, for all tones, $\xi_3 > 1$, in fact the effect of passing to III. is the same as if we halved the resistance of the receiver.

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[*] It is much to be desired that some of the above observations should be repeated by some one with a better ear for pitch than mine. I believe that very close accordance between theory and experiment would be brought out. I have not pushed either the theory or the experiments so far as I might have done, on account of my comparative obtuseness in the matter of pitch.

The following table, calculated for $R=6$, $S=14$, $L+N=\cdot 004$, will show the dependence of the ratio $\xi_3 : \xi_1$ upon n :—

n^2	10^5	10^6	10^7	10^8	10^9	10^{10}
$\frac{\xi_3}{\xi_1}$	2·37	2·24	1·62	1·13	1·01	1·00

The condition for $\xi_3 > \xi_2$ is

$$(2N-L)(2N+L)n^2+S^2-R^2>0\,.$$

For $\xi_1 > \xi_2$,

$$(2N-L)(2N+L)n^2-R\left(R+\frac{4}{3}\right)>0\,.$$

These formulæ explains the results above described.

The following theory includes experiments 4 to 7 :—

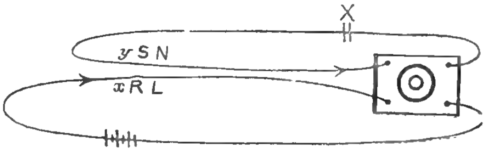

Fig. 5.

Let the current strength, resistance, and self-induction of the main and neighbouring circuits be xRL, ySN respectively, their coefficient and mutual induction M, and let there be a condenser of capacity X in the neighbouring circuit.

Then
$$(LD+R)x+MDy=A\sin nt\,,$$

$$MD^2x+\left(ND^2+SD+\frac{1}{X}\right)u=0\,,$$

$$(\alpha+\beta D+\gamma D^2+\delta D^3)x=A\left(\frac{1}{X}+SD+ND^2\right)\sin nt\,,$$

$$(\alpha+\beta D+\gamma D^2+\delta D^3)y=-AMD^2\sin nt\,,$$

where

$$\alpha=\frac{R}{X}\,,$$

$$\beta=\frac{L}{X}+RS\,,$$

$$\gamma=LS+NR\,,$$

$$\delta=LN-M^2\,.$$

If $A^2\xi$ denote the square of the amplitude of x ,
$A^2\zeta$ " " $x+y$,

then

$$\xi=\frac{\left(\frac{1}{X}-Nn^2\right)^2+S^2n^2}{(\alpha-\gamma n^2)^2+(\beta-\delta n^2)^2n^2},$$

$$\zeta=\frac{\left\{\frac{1}{X}-(N-M)n^2\right\}^2+S^2n^2}{(\alpha-\gamma n^2)^2+(\beta-\delta n^2)^2n^2}.$$

Experiment 4.—Here the neighbouring circuit consists simply of the other coil of the differential telephone. From the way the coils are wound, we have approximately $M=N=L$. To get the case where there is no condenser, we put $X=\infty$. We thus get, denoting by ζ_1 and ζ_2, the values when the neighbouring circuit is open and closed respectively,

$$\frac{\zeta_1}{\zeta_2}=\frac{\left(1+\frac{R}{S}\right)^2L^2n^2+R^2}{L^2n^2+R^2}.$$

Thus the effect of closing the neighbouring coil through an inductionless resistance is the same as if we increased the self-induction of the main circuit by the fraction $\frac{R}{S}$.

The intensity of all tones is therefore diminished, and more diminished, the less the resistance through which the neighbouring coil is closed.

The higher tones are much more deadened than the lower, so that the quality of the sound is flattened.

The following table shows the theoretical value of $\frac{\zeta_2}{\zeta_1}$ for different frequencies. If m be the number of vibrations per second, then $n=2\pi m$, and we have roughly, for $R=20$, $S=15$, $L=\cdot004$ (the units being ohms and earth quadrants).

Name of Note.	m.	n^2.	$\frac{\zeta_1}{\zeta_2}$
C	66	$172\cdot10^3$	1·03
b'	503	10^7	2·3
g'''	1592	10^8	4·5
e^{v}	5033	10^9	5·3

Experiment 5.—If the second coil be closed through a resistance having a self-induction N', then we must put $N=N'+L$, $M=L$. The above formulæ, then, lead us to the conclusion that the deadening effect will be less than it would have been on introducing the same resistance without induction if

$$N' > \frac{2RS^2}{n^2L(R+2S)},$$

i.e., taking $n^2=10^7(b')$, $R=20$, $S=15+9=24$, $L=\cdot004$,

$$N' > \cdot0085 .$$

In the actual experiment N' was $> \cdot016$.

Experiment 6.—The measure of intensity here is ζ. If we denote the values when the neighbouring telephone coil is open, closed simply, and closed through a condenser of capacity X (microfarads) respectively by ζ_1, ζ_2, ζ_3, then

$$\zeta_3 = \frac{1+qX^2}{r-2sX+tX^2},$$

$$\zeta_1 = \frac{1}{r}, \qquad \zeta_2 = \frac{q}{t};$$

where q, r, s, t are obtained from the formulæ given for the next experiment by putting $M=N$, and making $c=0$.

For a given frequency $\frac{n}{2\pi}$, the capacity for which $\zeta_3=\zeta_1$ is (besides $X=0$) given by

$$X_0 = \frac{2}{n^2} \cdot \left(\frac{NR^2+L(LN-M^2)n^2}{N^2(R^2+2RS)+(LN-M^2)^2n^2}\right) 10^{15} .$$

All the quantities being measured in C. G. S. units except X, which is measured in microfarads. If $X < X_0$, then $\zeta_3 > \zeta_1$, if $X > X_0$, $\zeta_3 < \zeta_1$; when $X = \infty$, of course $\zeta_3 = \zeta_2$.

For a given value of nt, ζ_3 is a maximum for a certain value of X; if we call this value X_m, then

$$X_m = \frac{\sqrt{1+qX_0^2}-1}{qX_0} .$$

The following are the values of X_o and X_m for b', g''', e^v, and b^{vi}, for the case:—

$L=\cdot01$, $R=22$, $N=\cdot004$, $S=15$ (ohms and earth-quads.).

	n^2	X_o	X_m
b'	10^7	37·	12·3
g'''	10^8	6·85	2·85
e^v	10^9	·81	·39
b^{vi}	10^{10}	·083	·041

The effect of introducing a capacity is therefore as follows:—Every note is increased as the capacity increases from zero. For a certain capacity the increase is at its maximum; for a certain capacity still greater there is neither increase nor decrease, for still higher capacities the intensity of the tone is diminished. As we go down the scale of frequency, the capacity for which a particular note is sensibly increased, and that for which it is most increased, increases; so that the capacity which increases a certain low note most will be great enough to diminish a high one practically as much as if the condenser were short circuited. This explains the main part at least of the phenomena observed.

Experiment—

Let ξ_1, ξ_2, ξ_3 denote the values of ξ, when the neighbouring coil is open, closed simply, and closed through a condenser whose capacity is X microfarads. Then—

$$\xi_3 = \frac{1-2p\mathrm{X}+q\mathrm{X}t^2}{r-2s\mathrm{X}+t\mathrm{X}^2}\,, \tag{1}$$

$$\xi_1 = \frac{1}{r} \quad \xi_2 = \frac{q}{t}\,, \tag{2}$$

where

$$p = an^2 10^{-15}\,,\ q = (b+cn^2)n^2 10^{-30}\,;$$

$$r = d+en^2\,,\ s = (f+gn^2)n^2 10^{-15}\,,\ t = (h+kn^2+n^4)n^2 10^{-30}$$

Where again

$$a = \mathrm{N}\,, \qquad f = \mathrm{NR}^2\,,$$
$$b = \mathrm{S}^2\,, \qquad g = \mathrm{L}(\mathrm{LN}-\mathrm{M}^2)\,,$$
$$c = \mathrm{N}^2\,, \qquad h = \mathrm{R}^2\mathrm{S}^2\,,$$
$$d = \mathrm{R}^2\,, \qquad k = \mathrm{L}^2\mathrm{S}^2+\mathrm{N}^2\mathrm{R}^2+2\mathrm{M}^2\mathrm{RS}\,,$$
$$e = \mathrm{L}^2\,, \qquad l = (\mathrm{LN}-\mathrm{M}^2)^2\,.$$

If X_0 denote the value of X for which $\xi_1 = \xi_3$,
X_0' " " $\xi_2 = \xi_3$,

then

$$\mathrm{X}_0 = \frac{2(pr-s)}{qr-t}\,, \qquad \mathrm{X}_0' = \frac{qr-t}{2(qs-pt)} \tag{3}$$

The values of these functions are as follows:—

$$\left\{\begin{array}{l} pr-s = \mathrm{M}^2\mathrm{L}n^4 10^{-15}\,, \\ qr-t = \mathrm{M}^2\{(2\mathrm{LN}-\mathrm{M}^2)n^2-2\mathrm{RS}\}n^4 10^{-30}\,, \\ qs-pt = \mathrm{M}^2\{\mathrm{N}(\mathrm{LN}-\mathrm{M}^2)n^2-\mathrm{S}(\mathrm{LS}+2\mathrm{NR})\}\,n^6 10^{-45} \end{array}\right. \tag{4}$$

I take the case where

L = ·2 (earth-quad.), R = 70 (ohms), N = ·004 (earth-quad.), S = ·3 (ohms)

In point of fact, the coil with which the experiment was most striking had greater constants than these; but as its constants do not happen to be so accurately known to me at present, and as the general features of the experimental results were the same in both cases, I have taken the case whose details I know best.

It will be seen that the functions in (4) are positive in the case considered for values of n^2 down almost to the lower limit of hearing. Hence, throughout the range of audibility, X_0 and X_0' are positive, and $X_0' > X_0$.

Now we may write

$$\frac{d\xi_3}{dX}=\frac{qr-t}{\{\&c.\}^2}\left\{-\tfrac{1}{2}X_0+X-\frac{1}{2X_0}X^2\right\} ;$$

so that when $X=0$, or $X=\infty$, $\frac{d\xi_3}{dX}$ is negative. Hence the values

$$X_m=X_0'-\sqrt{X_0'(X_0'-X_0)}\ ,\ (<X_0)\ ,$$
$$X_m'=X_0'+\sqrt{X_0'(X_0'-X_0)}\ ,\ (>X_0')\ ,$$

correspond to minimum and maximum values of ξ_3

These results contain the whole of the mathematical theory. The following table is calculated roughly for the above values of L, N, R, S, and will give a clear idea of the progression of the different quantities, as we proceed up or down the scale of audible notes. ξ_3', ξ_3'', ξ_3''' correspond to capacities of 1, 10, and 100, microfarads respectively.*

pprox. ame of Note.	n^2	ξ_1	ξ_2	ξ'_3	ξ''_3	ξ'''_3	X_0	X'_0	X_m	X'_m
G_1	10^5	11·1	14·6	11·1	11·1	10·9	5217	—	—	—
e	10^6	2·2	4·5	2·1	2·1	1·5	333	375	250	500
b'	10^7	·25	·60	·25	·088	·82	32·4	35·6	24·9	46·3
g'''	10^8	·025	·062	·016	·090	·063	3·16	3·39	2·51	4·27
e^{v}	10^9	·0025	·0062	·009	·0063	·0062	·316	·339	·252	·427
b^{vi}	10^{10}	·00025	·00062	·00068	·00062	·00062	·0316	·0339	·0252	·0427
g^{vii}	10^{11}	·000025	·000062	·000062	·000062	·000062	·00316	·00339	·00252	·00427

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* To avoid all possibility of misconception, I may repeat that the above table is calculated on the supposition that the amplitude of the disturbing electromotive force is independent of n. The comparison for the present purpose goes by horizontal rows.

If it be desired to compare vertically, and an approximation to the case of a telephone sender be contemplated, then the values of ξ_1, ξ_2, ξ_3, &c. must be multiplied by the respective values of n^2. Thus the values of ξ_1, become 11, 22, 25, 25, 25, 25, 25, those of ξ_2, 15, 45, 60, 62, 62, 62, 62; so that the quality (*i.e.*, the ratios of the intensities of the tones of different pitch) would be little altered by telephonic transmission in the two cases, if we except *very low* notes. This agrees with the general conclusions of HELMHOLTZ (Telephon und Klangfarbe, Wied. Ann. N. F. v. p. 448).

The same remark does not apply to the case where a condenser is introduced, a case not con-

It appears, therefore, that simply closing the neighbouring circuit increases all the tones of a composite sound. For very low tones the ratio of increase is less than for high tones; but somewhere above b' this ratio becomes practically constant. Hence, the whole effect will be general increase of intensity with a certain amount of sharpening in quality.

If we introduce a condenser, the result will be as follows:—

If the capacity be below a certain small quantity, the effect will be nil; if above a certain very large quantity, the effect will, as might be expected, be the same as if we closed the neighbouring circuit simply.

If we increase the capacity from the lower limit, the effect on a given tone will be as follows:—At first its intensity is diminished, and goes down to a minimum; then it increases again, and for a certain capacity is unaltered; on still further increasing, the intensity rises to what it would be if the neighbouring circuit were closed simply; then it reaches a maximum, after which it falls off again to the value it has when the neighbouring circuit is closed simply.

As we descend in the scale of audibility, the critical values of the capacity increase (ultimately more rapidly than at first). Hence the effect on a composite sound of increasing the capacity is to lower the tones most affected. Thus for a certain small capacity the low tones are comparatively unaffected, or even diminished; while the high tones are reinforced, there is then very marked sharpening. For a certain greater capacity the higher tones are all increased in the same ratio, while certain low tones are increased in a greater ratio; there is then flattening, though it may not be so very apparent in certain cases, owing to the diminishing of tones lower still.

The effect of the condenser is therefore partly (but only partly) analogous to that of a resonator which reinforces certain tones to the neglect of others.

The above theory explains the result obtained by GRANT, and, as far as my judgment goes, the additional results which I observed in my repetition of his experiment in a more striking form.

The discussion of experiment 8 would introduce nothing new after what has already been said, I therefore omit it.

In conclusion, I should like to mention another cause that may have played some part in certain of the above experiments.

Comparing the electrical oscillations to the vibrations of a gross material system, it will be observed that I have been discussing above merely *forced vibrations;* but there are also natural or free vibrations. Let us take the simple case of a condenser of capacity X, discharging through a circuit of

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templated of course in HELMHOLTZ's theory. It is one of the points of the above investigation to have (I hope) made clear the exact nature of this peculiar class of exceptions to the general statement that the telephone does not greatly alter the quality of the transmitted sounds. In connection with this matter I may refer to an exceedingly interesting little paper by HAGENBACH, Wied. Ann. N. F. vi. p. 403.

resistance R and self-induction L, as was shown long ago by Sir WILLIAM THOMSON, the discharge will be oscillatory if $R<\sqrt{\frac{4L}{X}}$. The variation of the current is given by

$$e^{-mt}\sin nt$$

where
$$m=\frac{R}{2L},\quad n=\sqrt{\frac{1}{LX}-\frac{R^2}{4L^2}}.$$

If we take the second coil of the differential telephone in experiment 5,

$$R=15\text{ (ohms)},\quad L=\cdot004\text{ (earth-quad.)},\quad X=\cdot3\text{ microfarad},$$

$$m=1\cdot9\times10^3,\quad \frac{n}{2\pi}=\frac{1}{2\pi}\sqrt{8298\cdot105}$$
$$=4585.$$

The frequency therefore corresponds to a note well within the limits of hearing, and since $\frac{n}{m}$ is not very small, a number of oscillations would take place before the currents were much damped. A note due to a free oscillation of this kind might therefore just have been heard in experiment 5. Of course the problem is in reality not quite so simple as the above, owing to the influence of the neighbouring coil. An exact solution could easily be given if there were experimental data that could be relied on to test it. It is simply a matter of the roots of a cubic equation.

I made a somewhat simpler experiment by alternately charging a microfarad by means of three Le Clanché cells, and discharging it through a telephone whose self-induction was about ·004 (earth-quad.). The sound of the discharge could be heard very well, whether the resistance of the circuit was 25 ohms or 10,000; but the character of the sound was very different, according as large or small resistances were used. The nature of the difference may be approximated to by pronouncing the words *pop* and *pink;* the former representing the sound with large, the latter that with small resistances. It would appear, therefore, that a certain high note is actually heard when the resistance is small, which is absent with large resistances. But this question is one for better musical ears than mine, and it is, moreover, an acoustical as well as an electrical question; for high notes of the kind are heard on simply tapping the ferrotype plate of the telephone with a pencil, so that this note might not be due to an electrical oscillation at all, but merely a free vibration of the plate exerted by the impulse arising from the magnetic action of the momentary current.

Since the above was written, I have seen the description of an experiment by RÖNTGEN which bears on this subject, the significance of which he clearly points out. The current in the primary of an induction coil was interrupted, and the sound observed in a telephone inserted in the secondary with or without a condenser. The result was much like that described above. "Nature," xvii. p. 164.

Lord Rayleigh has, I believe, made a similar observation on the thud, which is heard (without a telephone) when the primary is broken. He found its pitch to vary with the capacity of the condenser introduced into the secondary.

The following list of memoirs on subjects related to the contents of the above paper may be of some use to English readers. I know some of them only through abstracts in Wiedemann's Beiblätter; but, so far as I am aware, there is not sufficient community between the results of any of them with the above to call for special mention, although there are of necessity points of contact.

Du Bois Reymond, Archiv. f. Physiol., 1877.
Helmholtz, Wied. Ann., N. F. v. p. 448 (1877).
F. Weber, Abs. Wied. Beibl. iii. p. 291 (1878).
Lorenz, Wied. Ann. N.F. vii. p. 166 (1879).
Niemöller, Wied. Ann. N.F. viii. p. 656 (1879).
Aron, Wied. Ann. N.F. vi. p. 403 (1879).
Hagenbach, Ibid. p. 407.
Wietlisbach, Abs. Wied. Beibl. iii. p. 650 (1879).
Hughes, Phil. Mag. vol. viii. p. 50 (1879).
Lodge, Phil. Mag. vol. ix. p. 123 (1880).
Grant, Phil. Mag. vol. ix. p. 352 (1880).

XXII.—*Notice of the Completion of the New Rock Thermometers at the Royal Observatory, Edinburgh, and what they are for.* By Professor PIAZZI SMYTH, Astronomer Royal for Scotland.

(Read 5th July 1880.)

INTRODUCTORY ACCOUNT.

On the 26th of last month the full year appointed by Government Contract for the testing of the new Rock-Thermometers having expired, and they having approved themselves at all points, been accepted, and set fairly afloat on a new course of observation,—I hasten to announce the event to the Royal Society, Edinburgh, who have long had a lively interest both in these instruments and in the problems they have been employed upon.

Those new thermometers, viz., four more or less gigantic and deeply sunk in the rock, supplemented by two smaller ones for surface and air temperatures, are almost exact counterparts of the former magnificent set, which was so wilfully and calamitously destroyed by a Portuguese madman early one September morning in 1876, after having been continuously recorded at the Royal Observatory, Edinburgh, ever since 1837.

Now those earlier thermometers were constructed at that date by Messrs ADIE & SON of this city, at the expense of the British Association for the Advancement of Science, but according to the plans of Professor JAMES DAID

Forbes of the Edinburgh University; and if there was any one thing in Nature or Art which that eminent Natural Philosopher understood more intimately than another, it was the making of observations upon heat. Every one therefore of that day was perfectly satisfied with his being the sole scientist to give the design, and in the then resident member of the Adie firm, viz. Mr John Adie, being the mechanical artist to execute it.

But when, after the lapse of forty years, our calamity of 1876 occurred, and leave was after a while, or in 1877, granted by Government to get a new set of this species of thermometer made,—both James David Forbes and the humbler John Adie had long since passed away, and no one had applied meanwhile for any more of such colossal instruments. The still continuing firm however of Adie & Son bravely undertook the new order; Mr Richard Adie occasionally came here from his establishment in Liverpool, and I am breaking no confidences, and doing that firm more good than harm in saying further,—that they have now in Edinburgh as foreman, one who, still young and rising, has been found equal to the occasion; who entered into the work with a fine enthusiasm, and continued either to perform, or immediately superintend every part of it, up to its successful termination,—this person being Mr Thomas Wedderburn.

Now it is said to be a general law of human nature, that the very same works or events are intuitively described by different men according to their own several parts and responsibilities therein. Wherefore, to obtain a good account of the real making of these long thermometers (the longest of them several feet longer in the stem than the hall of this Society is high), it was my duty, not to try to write the account myself, but to go to the practical artist in the matter, viz., Mr Wedderburn, and ask him for his account of his own doings.

Accordingly at the end of this paper I have to thank him for enabling me to give, after a copy of the contract, and then some comprehensive remarks by Mr Richard Adie,—his own, Mr Wedderburn's, account of how every thing was done, from the first clearing out of the old bore-hole 3 to 5 inches in diameter and 26·5 feet deep in the solid porphyry rock of the Calton Hill, to the final placing of the new set of thermometers therein, after two winters of anxious, careful testing of the zero points and deciding on the scales.

All that, together with many *naive* and very much to the purpose remarks on the several practical processes that had to be gone through, should be read, when printed, in Mr Wedderburn's own words, which are authoritative there. But now when his work is over, and the thermometers are in regular course of observation at the Royal Observatory, a new class of questioners may arise, demanding to be told what it is all for? and why would not smaller and cheaper thermometers have answered as well? In which case it is I who have to come to the front and try to explain.

And yet, in the first portion of my reply, it is not merely I that speak, but far more the spirit of that grand scientist of Scotland in the last generation,—James David Forbes. He, in his deep and earnest studies of nature, desired to obtain numerical expressions for certain Natural Philosophy constants; such as, given the summer heat, the winter cold, and the daily variations on the surface of the ground, together with the physical rock below,—at what rate do those temperatures and variations of the same travel downwards towards the centre; the results being required accurate to the hundredth of a degree Fahr., and a fraction of a day as to time.

The only mode of correctly ascertaining these data free from very large and possibly ruinous disturbances, was then well considered to be, the having thermometers large enough to allow of their bulbs being set in the heart of the rock, at every required depth, viz. 3, 6, 12, even 24 feet, while their scales were on the surface of the ground.

The necessary expense was therefore most willingly incurred, though in the economical days of forty and more years ago; together with the labour of observing for many seasons. Not only too the Observatory set of thermometers, but two other sets like it, one at the Craigleith Quarry, and the other at the then Experimental Gardens. And these measures proved successful; for the problem was at length solved by them; in a manner and with a completeness too, not only to satisfy Professor Forbes himself,—after whose passing over a scientific field, there was little enough left for any one else to glean—but to well content the Royal Society, Edinburgh, also. For the Society printed the Professor's noble Memoir on the subject in their Transactions for 1845–46 (Vol. XVI.), and crowned it with a prize.

Soon after the above clenching event, the other two sets of thermometers were reported broken; and the question then came before me, in my official capacity at the Royal Observatory,—what shall be done with the one remaining set of rock thermometers there?

After consulting with Mr Alexander Wallace, the Assistant-Astronomer, who had carried out, under my predecessor, Thomas Henderson's, supervision, all the previous observations for Professor Forbes from the first,—I decided that they should continue to be observed; largely because I believed them to be the best set of rock-thermometers in the world, and also because there is still an immense deal connected with the temperature of man's planetary abode, which he has not mastered yet. So the observations were continued without a break, and before long another practical use did appear for them;—thus,—

The Transit Instrument in the Royal Observatory, Edinburgh, had been known to my predecessor to be affected with an annual fluctuation of level from East to West, nearly in accordance with the readings of a small thermometer under the floor of the building; and there was a belief in the community at large, that that level effect was produced by the afternoon Sun shining on, and expanding, the rocky western side of the Calton Hill. Wherefore also, said various wise men, "the rock foundation of the Edinburgh Observatory is just about the worst sort of foundation that could possibly have been selected for an accurate, meridian, Astronomical Observatory."

But on examining the dates and configurations of the curve representing each annual progress of the level fluctuations, and comparing them with the similar points of the annual temperature curves of the several rock Thermometers,—I was presently able to demonstrate, that what particular thing or matter the heat was acting on to disturb the instrument's level,—so far from being any rock-surface, more than 200, or even only 20, feet off, must be within less than 3 feet from the instrument itself. And it has been experimentally proved since then to depend on the abnormal expansion of the mountings of the instrument within its own chamber. While the grand porphyry rock of the Calton Hill has at the same time been shown to be fully worthy of supporting a much grander and more celebrated Observatory than has yet been erected upon it.

Again, in following years, these rock thermometer observations were discussed by Sir WILLIAM THOMSON, and by aid of his suggestive philosophy and powerful analysis made to indicate the beginnings of some vast and soul-elevating results; such as

First, the amount of the Earth's central heat which is still year by year escaping through the surface and radiating into space; and

Second, setting forth something as to the age of that heat; or the time which has elapsed since the whole earth was of a life-forbidding, because light-emitting, temperature. Of these high reasonings the Society has already heard at various times from that eminent philosopher, and it is hoped will further hear from him directly again and again.

More than thirty years had thus passed by. Our stock of observed temperature facts of the Calton Hill was always growing, simply because we were an Observatory, and not any other kind of institution, however estimable; and presently a third supplementary useful purpose appeared, quite different from any of the former, and fraught with practical applications for the future, of no ordinary kind.

What is so important to both the business and pleasures, the life and the glories of this country of ours, as the seasons of summer and winter; and who does not know their intimate dependence on the physical nature of the Sun, combined with the grandly ordered angle of the Obliquity of the Ecliptic, the rotation of the Earth on its axis, and the whole globe's envelopment in a most composite atmosphere, of permanent gases and watery vapour! But then again who does not also know, by even terrific personal experience, that there are occasionally summers in this country *and* summers; winters also *and* winters; though why or wherefore, is still a scientific mystery.

Taking up then that particular subject, in 1869, by means of our accumulated years of observation of the rock-thermometers, I tried a simple method of eliminating the effects of the ordinary seasons; and then examined closely the residual quantities. They might of course be expected to indicate *some* variations with time; and the one all important question for the hopes of science was, would it be regular, or irregular?

Great therefore was my joy when the result said immediately, for all the larger variations, REGULAR! Regular even to a surprising degree, for this was the order that came out;—Every eleven years nearly (and this three times over in succession during the limits of our observations, so that there could be no mistake about it), a wave of heat had struck the earth's surface from without (not from within, as proved by the dates being later and later according to the depth of each thermometer); and between those most signal eleven year heat epochs, there was no other hot wave of a supra-annual order, which could compare with what occurred then, for either size or intensity.* Their dates were 1846, 1857 and 1868.

That was the first law of occurrence deduced by the inquiry; and the second, approaching to something like a cause, was—that each of those dates was found to mark the beginning, the well commenced beginning too, of precisely the most intense period of a well-known cyclical habitude of Solar activity;—acting doubtless, both by its increased heat and other radiant emanations, though chiefly observable to man by an accompanying optical phenomenon, "the Sun-spots."† And, after that was settled, then came the third law of occurrence, viz. that close on either side of the heat wave, or more exactly 1·7 year therefrom, came a specially cold trough. Sometimes the preceding, sometimes the following of these cold waves was the severer of the two; but the curious rule of two was always kept up at every successive cycle; and for reasons most probably of terrestrial physics which are exceedingly interesting, but too long, and far from our subject, to be entered on here.

Practically confident then that this new mode of treating the accumulated observations of our rock thermometers, had helped me to a most important

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* These epochal waves of heat may apparently come to a head at any time in the course of a year; but are never so powerful as to destroy altogether the ordinary summer or winter. If therefore one, of any cycle, occur just at mid-winter, it merely makes it an unusually mild winter; not a season as hot as, or hotter than, an ordinary summer.

† These Sun-spots have been proved, by Professor LANGLEY and others, to have no power in themselves to produce any notable alteration in the quantity of the Sun's radiant heat practically felt by the earth and its atmosphere; but bear about the same relation to it, that the cinders dropping into the ash-pit of a steam engine's fire-place, do to the amount of mechanical work being performed by the engine at the moment; and if the engine itself is not observable by us, it is well to note and reason on the number and size of the red-hot cinders, and the rate at which they fall.

beginning of a higher Meteorology,—I sent up, in March 1870, a full account of the affair, with a copy of all the original observations for thirty-three years to the Royal Society, London. Unfortunately that learned Society had not then begun to perceive the bearing of Solar physics on variations of terrestrial climate, as, through a Committee, it is now professing to do, and is corresponding about with H.M. Government: so, in their then state of knowledge, they summarily extinguished my paper, and buried it out of sight.

But no matter! For was I not freed thereby to print some of the originals of the Manuscripts, which I had fortunately preserved, in the next issuing volume of the Edinburgh Astronomical Observations, the thirteenth of the series, early in 1872? Of course I was; and I also took that occasion to go further, and announce (see Appendix 4 to this paper), that the next very cold period would not take place until 1878·8,—*i.e.,* near the end of the year 1878—and that the next hot period would occur in 1880! Making thus two distinct statements for critical and opposite kinds of weather in this country, and to an unheard of distance of time beforehand, to have any ordinary chance of success.

But having been permitted to live and publish that most crucial, double-headed conclusion in 1872, alas! that I had not died thereupon, and simply left those numbers behind me, pure, untouched and in all their integrity. For then, when those two dates, predicted so many years beforehand by one who was no longer in the way of troubling, no longer in rivalry with any one, should have come round,—and been found by a new race of scientists to be so remarkably close to the subsequently observed leading features of meteorology which followed,—better men than I would have rushed into the subject in crowds, and a whole new science might have been born in a day.

But it was ordered that I should not die then and there; but should live on; and after five years, stumble, and spoil everything by one unhappy slip; for this is the dismal version of what ensued.

Our hopes of future confirmations had been growing continually more precise with every additional year,—when suddenly, in the autumn of 1876, befell us that ever regretable calamity, of the mad-man climbing in the dawn of early morning over the dilapidated Observatory boundary wall, and smashing our staff of strength, the whole of our rock thermometers. After that loss, I knew no more of the march of earth-temperature, than any one else in the community; and in my ignorance was blown hither and thither by vague surmises. So that when in 1877, one continental scientist announced that the then, and still the last, Sun-spot minimum occured in 1876·8, and another said 1877·5,—I was wise enough to recoil from the former, but stupid enough to believe the latter, and act accordingly. For that latter date being a year earlier than what, in 1872, I had hypothetically taken for the next Solar-spot minimum,

—I felt obliged, when republishing on the matter in our volume XIV. in 1877, to say,—that both the coming cold, and the coming hot, seasons before alluded to, would each of them arrive a year earlier than previously stated.

Fatal mistake! For when the thus erroneously amended date for the then approaching cold season, or the winter of 1877 and 1878 arrived, and was not a cold one; and the similarly amended date 1879 for the following warm season, and was not warm;—how instant every one was then to cry out against the error, to be scandalized at it, and to point the finger of scorn, not only at me, which would have been excusable enough, but at the whole subject of Solar physics, and at the Royal Observatory on the Calton Hill too!

One prominent patron of Science had even gone so far as to say:—"There is no evidence to show, that there is any more connection between Sun-spots and famines, than there is between comets and wars, or planets and the death of kings."

That was darkness indeed,* and looked then as if it was going on to

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* In Mr George F. Chambers' "Handbook of Astronomy," 3d edition (Clarendon Press, Oxford), there is an immense amount of well-collected, useful information, in the course of the first chapter, on the Sun-spots and their influence, first on the magnetism, and then on the Auroras of the weather of the earth, as determined by a positive crowd of first-rate and honourable observers, mathematicians, astronomers, and physicists.

Closely following on M. Schwabe's announcing the periodicity of Sun-spots, there were published in 1850 to 1852 a series of almost simultaneous but independent discoveries and demonstrations by Professors Lamont of Munich, Gautier of Geneva, Wolf of Zurich, and General Sabine of London, of the close connection between Sun-spots and the earth's changes of magnetism, so that, not only were the periods the same in the whole, but the maxima and minima were conformable also. While still more pointedly, when in 1859, a terrestrial magnetic storm of unprecedented magnitude occurred from August 28 to September 7, it was shown by Professor Balfour Stewart ("Philosophical Transactions," 1861, p. 423), that this was synonymous with the period of maximum activity of one of the largest Sun-spots ever observed. (See a Physical Treatise on Electricity and Magnetism, by J. E. H. Gordon, B.A., 1880, vol. i. p. 197.)

Whereupon Mr Chambers quotes the shrewd and far-seeing Manchester scientist, Mr Baxendell, as considering,—"That diversities of solar activity are to be regarded as causing changes in the magnetic condition of the Earth, and so producing changes in the directions and velocities of the great currents of the atmosphere, and in the distribution of barometric pressure, temperature, and rainfall." And he expressly lays down further on, that "the future progress of meteorology must depend, to a much greater extent than has generally been supposed, upon the knowledge we may obtain of the nature and extent of the changes which are constantly taking place on the surface of the Sun."

Mr Chambers quotes also Professor Balfour Stewart for proving that a bond of connection exists between Sun-spots and these three terrestrial features—magnetic declination, "earth currents," and Aurora; also Professor Loomis of America, as having well remarked through long periods, the connection between Sun-spots, magnetic declination and Aurora, and given an effective map of them.

Also M. Pöey, for the connection of tropical storms with the maxima of Sun-spots through more than a century.

Also Mr Elvirs of Canada, for connection between Cycles of Sun-spots and rainfall frequency.

Also the Oxford Observatory, for connection between Sun-spots and the mean direction of the wind; the westerly element increasing with the amount of spots.

Also Mr Stone, at the time Astronomer Royal at the Cape of Good Hope, and equally M. Abbé of Cincinnati, but then discussing Munich observations; for they were each led to a connection between Sun-spots and terrestrial temperature.

Again, since the date of 1872, Mr Norman Lockyer, F.R.S., Dr W. W. Hunter (Statistician dominate every one and every thing. But meanwhile a most unexpected ray of light had beamed upon us here in Edinburgh. Urged to it, as I am happy now to confess by my Wife, and having had all along some suspicion of those foreign accelerated dates for the Sun-spot minimum, I took to observing Sun-spots myself. Only in a rough way and at home; but it was enough! For I soon found that the minimum had by no means taken place in 1877·5; but was delayed until 1879 was begun. And not indeed until 1879·8 was there any very decided manifestation of the Solar forces of a new Cycle in strenuous action. But at that date one morning, something so signal was witnessed in the Sun, that I wrote of it the same day to "Nature," under the title of "Sun-spots in earnest;" and five months after that, on the strength of a certain night observation, wrote of "The Aurora at last." Since the publication too, I have been doubly confirmed as to the Sun-spots from the Royal Observatory, Greenwich; first by the chief Assistant Mr CHRISTIE, writing to "Nature" after seeing my Sun-spot letter there, and detailing similar observations at Greenwich; and second, by the Astronomer Royal, Sir G. B. AIRY, in his late annual Report, expressly giving the same dates, viz., the beginning of 1879 for the epoch of the minimum of Sun-spots, and October 1879 as a later date from which period onwards and ever since, the display of spots has been large and generally increasing. The return of the Aurora was also confirmed, first by a disturbance of the magnets at Greenwich on the same night,* and then after a while by a Canadian observer (Colonel BULGER) announcing that after a long barren interval an Aurora had at last appeared there, on the same evening that I had observed it in Edinburgh, and so like it in character that my description in "Nature," of the Edinburgh phenomenon would have served for the Canadian one as well. And now a Scandinavian Professor,† at Bergen in Norway, is advertising in "Nature" (No. 567, vol. xxii. for July 1, 1880) for Auroral observers; because in the next few years he expects Auroras to be so much more numerous and intense than they have been for years past.‡

General for India), Mr MELDRUM of Mauritius Observatory, Professor STANLEY JEVONS of London University, and Professor DOUGLAS ARCHIBALD have written so much both separately and combinedly on Sun-spots, Indian rainfalls, and Indian famines, ship assurances in the Tropics, and commercial panics, and become so widely approved therein, that I need only allude to them here by name. Though it has not been sufficiently brought out yet that Dr W. W. HUNTER received, apparently, his earliest ideas on the subject somewhere in 1875, from Mr N. POGSON, Government Astronomer at Madras, who was then in rather low spirits *because* he was expecting a famine in the next year; and expressly, as he particularly explained, on account of the approach of the period of a minimum of Sun-spots; which famine did take place, and with all the disastrous consequences to life in India, and purse in Great Britain, which the daily papers have chronicled since, but Mr POGSON saw feelingly so long beforehand.

* The disturbance of the Earth's Magnetism appears to have been noticed the same night at Vienna and also at Lisbon; see "Nature," p. 220, No. 558, vol. xxii. or for July 8, 1880.

† SOPHUS TROMHOLT, Professor of Mathematics.

‡ Some of these were closer than he was aware of, for on August 11 and 12, summer season though it was, the most magnificent of coloured Auroras were witnessed over a large part of England

So with 1879·0, now sur-abundantly proved to be the real date of that typical solar phenomenon, the last minimum of Sun-spots—which serves so usefully on this inquiry as a finger-post, or mile-stone of Solar physical energy, —I applied on to that, as an absolute date, our thermometrical differences as before; and behold, the result was almost perfect! For the very acme of the cold season came out just as it was experienced by every one in the end of 1878 and beginning of 1879. And the following warm season is now upon us, increasing from day to day, exactly as the whole series of rock-thermometer observations long ago taught us, it ought to do at this time.

Hence we may most certainly accept,—that if that admirable book of scientific predictions, the Government's Nautical Almanac (which publishes four years beforehand several thousand minute particulars of the coming places of Sun, Moon and Stars), had only been enabled, by high learning and physical knowledge, to add thereto in 1876, the true date of the then impending minimum of Solar-spots,—the cold season of 1878 and 9,—which the country had already been preliminarily and approximately warned about by me in 1872, —would have been most exactly spotted in 1877, or a full year and a half before it began. In which case Agricultural Science would doubtless have bent itself to a new task; and, elaborating some variation of farming for 1879, suitable to a cold and wet year, might have saved no small portion of the hundred and fifty millions of pounds sterling which are said to have been lost in that year throughout Great Britain; and largely because the character of the season was generally unexpected, and therefore totally unprepared for.

This then is the last of several insights into Nature, which the first set of rock-thermometers, by their forty years of observation, have just brought us in view,—not put us altogether into possession, of. For there remain many smaller variations of the cyclical quantities to be explained. And in order to give a clearer idea of both what has already been accomplished, and what remains to be done, I have, with obliging assistance from Mr BUCHAN, who is Scottish Meteorology personified, and with help from the two assistant Astronomers on the Calton Hill, prepared a collection of various observations from 1821 to 1880, in Appendix 5; inclusive of course of our own rock thermometer results in a condensed shape; and also such Sun-spot dates as I have been able to gather; those of the immortal discoverer of their periodicity, M. SCHWABE, being always preferred wherever they exist, viz., 1826 to 1863.

A large Plate, No. XV., further represents these quantities graphically; and the whole, should it be approved and advocated by this Royal Society, may perhaps strengthen the hands of Government in doing for Sun-spots and Solar

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and Scotland, accompanied by the most violent magnetic storm that had been felt for many years (see "Nature," p. 361, No. 564, vol. 12; Aug. 19, 1880); while the Mean Temperature of that month turned out higher than for any August (that of 1857 excepted) chronicled by the Meteorological Society of Scotland, September too followed, with the same temperature characteristic.—*P. S.*, Oct. 1880.

physics generally, what they have done with universal commendation, for the Moon during two centuries; viz., kept a Royal Observatory continually observing it, until at last the said Observatory is able, now very nearly, to predict the Lunar places for future years from its own observations, and with all the extreme accuracy demanded by the advanced national requirements of the present time.

APPENDIX

No. I.

(Contract for the New Rock Thermometers.)

Estimate by Alex. Adie & Son, 50 Princes Street, Edinburgh, for Underground and Standard Thermometers to be placed at the Royal Observatory, Edinburgh.

6th February 1877.

Six thermometers of the following lengths, including the scales above ground:—One 23 feet, one 13 feet, one 6 feet, one 4 feet, one 2 feet, one 1 foot, to hang in air-box. These thermometers to have gun-metal scales, with a strip of platina half-an-inch wide inlaid in the gun metal to receive the graduations and resist oxidation. The bulbs of four of the above thermometers to be cased in copper cylinders, and packed therein with fine clay. Iodine to be used for colouring the alcohol. The thermometers to be carefully compared weekly and daily, with three mercury standards to be, as below, from the time of being made until insertion, that is while the temperature permits this being done,	£140	0	0
The three necessary mercurial standard thermometers above alluded to, to be prepared with all necessary attention to high scientific accuracy, finished with scales like the first six, to be 16 inches long, and to range from 30° to 220°.	18	0	0
A pine wood box with luffer-boards, made for free ventilation, fastened to the rock with copper fastenings, the door to have a brass lock and hinges; also one pine wood box to fit outside the above, to be 7 inches free all round, and to be fastened to the rock with copper bolts, the door locked with a brass lock. The doors of these two boxes to open outwards only,	17	0	0
Preparing well of rock in Royal Observatory grounds to receive thermometers, and filling same after insertion of the thermometers with fine clay,	21	10	0
	£196	10	0

Total amount, One hundred and ninety-six pounds ten shillings. The whole of the work to be performed to the satisfaction and approval of the Astronomer Royal for Scotland, who is to have the power to vary the specified length of the long thermometers to the extent of 30 inches each. All the above work to be maintained in good condition by our firm for the space of twelve months.

(Signed) Alex. Adie & Son.

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* The lengths for the five principal thermometers as eventually constructed were, from the surface of the ground down to the centre of each bulb, $t^1=250$ British inches; $t^2=125$; $t^3=50$; $t^4=25$; $t^5=1$; while above the surface of the ground every thermometer had 30 inches additional of scale length.

No. II.

Supplied by R. ADIE, Esq.

The Earth Thermometers in the Observatory Grounds, Calton Hill.

In the XIth volume of the Astronomical Observations made at the Royal Observatory 1849–54, there is, pp. 225–279, an account of the earth thermometers, with observations from 1837–54. This paper contains all the information in detail in regard to structure, and correction for surface temperatures on the stems of the long tubes. What is there stated applies to the thermometers inserted by us on 18th June 1879, in the bore of the rock occupied by the first set.

An accident destroyed the thermometers of 1837; to replace them it was necessary to clear the broken stems of the old tubes out of the bore. In doing so, we found the clay placed on the surface to have changed, through 42 years' exposure to rain, into a piece of hard rock, which held the glass tubes of the thermometer stems very firmly. After removing the stone containing the stems of the tubes, the sand and clay for a depth of six inches was partially indurated, when we reached the sand in the state that it had been inserted.

When the bore had been cleared of the old sand, we found that when empty it acted as a perpendicular drain, receiving water from the fissures in the rock which quickly passed away with dry weather.

In the new set of the thermometers, clay on the top of the sand has not been used, as we consider it unsafe to bind the tubes therewith; one of the 1837 set having been broken in a frosty morning when so bound. The scales of the new set of thermometers are platina, and fastened to their respective tubes with platina wire.

(Signed) ALEX. ADIE & SON, 37 Hanover Street,
8th January 1880.

No. III.

Account of the Making and Placing of the New (1877–79) *Rock Thermometers at the Royal Observatory, Edinburgh,* by THOMAS WEDDERBURN, Foreman of the Firm of ADIE & SONS, Opticians, Edinburgh.

On our receiving the order from Professor PIAZZI SMYTH for the reconstruction of the destroyed earth or rock thermometers, it was considered that, in the first place, the hole that they were sunk in should be cleared out, and on our clearing off the surface mould we found a hard compact substance instead of a "puddle clay" as mentioned in the Observatory Transactions. The sections of the tubes now being seen, we then found the substance to be about 6 inches thick in the hard state, and then gradually softening for other 3 inches until it came in contact with the sand that filled the hole. As it was wanted to be ascertained if the portions of the thermometers underground were the same in construction as what the new thermometers were to be, we proceeded to remove the hard mass, with the sections of the tubes, and then the sand, until we got down to the 3 feet thermometer bulb, which we removed; then to the 6 feet bulb, which was also removed; but on reaching down to the 12 feet bulb it was found to be firmly fastened to the side of the hole by the rust of its tin case, so that we had to give up hopes of bringing it to the surface. We then proceeded in a rough and ready way, by means of a 30 feet pole with 3 feet of 2 inch brass tube attached to it, to remove the rest of the contents of the hole, which was found to be 26½ feet deep, the opening at surface, 5½ to 5 inches, in diameter; the first 12 feet of it was much the same, after which it closes to a hole of about 3 inches diameter for the remainder of the depth. We may state here that we found some obstruction in removing the sand from a copper wire about the 20th of an inch in diameter. There having been no evidence of it when opening out the hole, we could only bring it up in small portions. On showing these to Professor ALEX. S. HERSCHEL of Newcastle-on-Tyne, he thought them to have been portions of a thermal pile (though no written note of such a thing has been found), and from the length of wire brought up it must have reached the bottom of the hole.

In proceeding with the construction of the new thermometers, we had carefully retained portions of each tube for the size of bore, and having applied to Mr FORD, of the South Back of Canongate, for these extra long tubes, we had them drawn on the 14th of August 1877. The first five tubes of 40 feet did not come up to what was expected of them, though for the shorter thermometers there were pieces of them that answered. It was then proposed to draw tubes of a 100 feet, instead of carrying on the drawing of the 40 feet lengths. On a 100 feet tube being drawn, it was found on careful examination to answer the purpose, 30 feet of it being cut from the centre. For the scale tubes we had eighteen drawn of 3 feet each, and after carefully callipering them, we found them sufficient to answer the purpose. After the tubes were drawn they were laid in their "gutters," which were made of 26-inch deals, set at right angles, with pieces of cork 3 feet apart for the tubes to rest on, where they remained until their insertion in the Royal Observatory grounds. In the drawing of the bulbs of the thermometers, we had carefully prepared sketches of each size, so that there was no trouble in working them, and we may mention that they were annealed, the glass of them being as near as possible the 20th of an inch in thickness.

In the making of the thermometers our first care was to find if we had got the bulbs of the right *size*, which we did by fixing a piece of the scale tube to each bulb, and then filling them with spirit, and testing them in the usual way with the standard, when they were all found to be correct for each range of bulb. We then attached each bulb to its own tube, and in the shorter thermometers filled them with the spirit in the usual way. With the 12 and 24 feet tubes we turned the bulb ends uppermost, and poured the spirit in through a small filler made of inch glass tube drawn to a fine point, until the bulb was nearly filled. The points of the bulbs were then sealed, and the thermometer reversed, and a small portion of spirit placed in the expansion bulb at top. Then warm water was applied to the bulb to expand the spirit and expel the remaining air; the air passing through the spirit in the expansion bulb, and allowing it to descend; when after a few applications of heat and cold, we had the satisfaction of seeing them filled.

Our next care was to regulate them, which was done in a tub of cold water, with the three standard thermometers made for the purpose, and having fixed the points as near as possible, we then had temporary scales of boxwood made and attached to each. They were then removed to Professor PIAZZI SMYTH'S house, at 15 Royal Terrace, for comparison with the three standards. In the work of comparing the thermometers, the bulbs were placed in a tub of water, so that they were always covered; the temperature of the water being carefully noted, as well as of the atmosphere, each time a reading was taken with the three standards. The readings through the winter of 1877 and 1878 were but few, from the mildness of the season and the thermometers being inside the house. Wherefore, to make more certain of the following winter season, the thermometers were removed to the outside of the house, where the final readings were got in the spring of 1879.

The three standard thermometers with which the comparisons of the long thermometers were made are a set that were made in 1867, of very fine tubes, the callipering being almost perfect. The points were taken in 1877, when these thermometers were finished; the scales of them being of gun metal inlaid with a strip of platina, on which the dividing is done. There is also a strong bar of gun metal on the sides of the scales to prevent their bending, owing to the unequal expansion of the two metals.

The final work of placing the thermometers in the hole was done on the 26th of June 1879. They were removed that morning from the Royal Terrace house to the Royal Observatory, where the copper cases were placed on the bulbs, and filled with plaster of Paris. In the bottom of each copper case there is a layer of cork, varying in thickness from 3 inches downward, cupped to receive the bottom of each bulb; the points of the bulbs being about an inch from the bottom of each case.

The placing of the 250 inch thermometer in the hole was done by having a cross spar at the top, having four pulleys, two of the pulleys being close to the tube, and the other two being 12 inches apart, over which was carried on each side a cord, the one cord being attached to the top of the tube, and the other to the copper case. The cord was then passed one on each side of the two outside pulleys, and made of sufficient length to reach the ground, when the case with the thermometer was placed erect. There was then placed a 3 lb. weight on each side, the effect being that when the case with the thermometer was placed against the triangle, and the thermometer freed of its tyings, it passed down of its own weight. Fine fresh water sand, specially procured for this purpose from an excavation in the Easter Road, was filled in for the 125 inch, which was passed down by hand, the others being done in the same way. On the following day the scales of platina were wired on, and the two wooden cases, or little houses for protection from the weather, fastened down with gun-metal bolts.

THOMAS WEDDERBURN,
Foreman of Adie & Son.

P.S. (1).—The following articles were taken from the hole:—

The hard block with the sections of the tubes, the 3-feet bulb with its tin case, the 6-feet bulb with its tin case, the remains of the 12-feet bulb tin case, the portions of copper wire, a sample of the sand used in filling up the hole, a piece of the supposed thermal-pile wire perfect, taken from the transit-house pipe that was supposed to have been once in connection with the hole, and is within 3 feet of its mouth. Of this arrangement no records are known to exist; and from 1845, downwards, the piece of lead pipe with a short length of the copper wire wrapped in cere-cloth, to insulate them, and struck through the east wall of old-transit house, had been considered the relics of some experiments once carried on by Professor J. D. FORBES, but not described, or subsequently cared for, by him. T. W.

P.S. (2).—The attachment of the big bulb to its long tube was done in the usual way by sealing up the tube at one end, and blowing a small oval bulb, and cutting away the half of it, the same being done with the stem of the big bulb, and then the two half bulbs on the tubes and stem being melted together by a Bunsen flame. T. W.

No. IV.

The Cyclical Seasons predicted in 1872.

Extracts from pp. R 105, R 106 of the XIIIth Vol. of the Edinburgh Astronomical Observations, published in the beginning of 1872. (Subsequent additions in parenthesis, thus).

" How intimately the well-being of the poor generally, as well as of the agricultural classes depends on those characteristics of weather (viz., cyclical returns at several, or many years' interval), which no scientific Society can at present foretell, and no Ministry prevent in their destructive effects to the national revenue when they do come" (has been proved in the famine history of the past, and may be repeated in the future, for we find as follows in the Edinburgh rock thermometers)—

"1. The most striking and positive feature of the whole series of observations" (viz. of the Rock Thermometers at the Royal Observatory, Edinburgh) "is the great heat wave, which occurs every eleven years and a fraction, and nearly coincidently with the beginning of the increase of each sun-spot cycle of the same eleven year duration. The last observed occurrences of such heat wave, which is very short lived and of a totally different *shape* from the sun-spot curve, were in 1834·8, 1846·4, 1857·8 and 1868·8; whence, allowing for the greater uncertainty in the earlier observation, we may expect the next occurrence of the phenomenon in or about 1880·0.

"2. The next largest feature is the extreme cold close on either side of the great heat-wave. We may perhaps be justified in concluding that the minimum temperature of the present cold wave was reached in 1871·1; and that the next similar cold wave (*i.e.* similar in being one or other of the two satellites attending on the heat wave, though that of 1871·1 was the *follower* of the 1868·8 heat wave, and that now spoken of as to come in 1878·8, is the *preceder* of the expected heat wave of 1880) will occur in 1878·8.

"3. Between the dates of these two cold waves (1871·1 and 1878·8), there are located, according to all the cycles observed,—3 moderate and nearly equi-distant heat waves, with their two intervening and very moderate cold troughs, but their characters are quite unimportant as compared with what is alluded to under heads 1 and 2."

(To the above it may now, or in 1880·9, be added—that the following satellitary cold wave after the heat of 1880, should occur in 1882, subject to some uncertainties dependent not only on the still inexactly ascertained epochs of several past minima, as well as maxima of sun-spots,—but on the total inability of all modern science up to its latest advanced position, to *predict* whether the date of the next maximum of sun-spots will be at a long, a short, or an average interval after the last minimum. The variations of those intervals in past cycles having amounted to anything within three years; an amount of uncertainty far too great to allow of useful agricultural warnings.)

No. V.

Scottish Meteorological Data of various kinds, arranged either in simple Annual, or more generally in Quadruple Annual Means for Cyclical inquiries.

TABLE I. Simple annual Means chiefly for SCHWABE'S Sun-spot curves, and WOLF'S dates of max. and min. of Sun-spots.

TABLE II. Quadruple annual Means of the Rock Thermometers, at Royal Observatory, Edinburgh, from 1837 to 1876. Pages 1 and 2.

TABLE III. Quadruple annual Means of Air Temperature, by Scottish Meteorological Society, 1856–1880.

TABLE IV. Quadruple annual Sums of Scottish Rainfall, by Scottish Meteorological Society, 1856–1880.

TABLE V. Edinburgh Air Temperature by A. ADIE, from 1821 to 1850, in Quadruple Ann. Means.

TABLE VI. Edinburgh Rainfall, by A. ADIE, from 1822 to 1850, in Quadruple Ann. Sums.

TABLE VII. Quadruple Annual Sums of Rainfall, at Culloden, from 1841 to 1862, to fill the gap between the last Rainfalls of A. ADIE and the first of the Scottish Meteorological Society.

TABLE I.—*Single Annual Means of the Edinburgh Earth-Thermometers, and others; begin with the first observations of* M. SCHWABE, *the discoverer of the Periodicity of the Sun-spots.*

(See Plate XV.)

Date.	t_1 or 25·6 British feet deep Therm.	t_2 or 12·8 British feet deep Therm.	t_3 or 6·4 British feet deep Therm.	t_4 or 3·2 British feet deep Therm.	Air Mean Temp. in Edin. by Alex. Adie.	Air Mean Temp. over Scotl. by Sc. Met. Soc.	Schwabe's New Groups of Sun-spots. Kew Obs. / Wolf's Nos. × 2.	Wolf's Sun Spots, Dates of.		Rainfall in Edinburgh, by Alex. Adie.	Rainfall over Scotl., by Sc. Met. Soc.
								Max.	Min.		
	° F.	° F.	° F.	° F.	° F.	° F.		Year.	Year.	Inches.	Inches.
1826·50	...	...	...	...	48·7	...	118	...	...	15·27	...
1827·50	...	...	...	..	47·1	...	161	...	...	32·59	...
1828·50	...	...	...	...	48·5	...	225	...	...	25·23	...
1829·50	...	...	...	...	45·2	...	199	1829·5	...	29·96	...
1830·50	...	...	...	...	46·0	...	190	...	...	33·25	...
1831·50	...	...	...	...	47·5	These numbers are only comparable *inter se.*	149	...	...	24·53	...
1832·50	...	...	...	...	47·7		84	...	...	23·23	Only comparable *inter se.*
1833·50	...	...	...	...	47·2		33	...	1833·8	20·88	
1834·50	...	...	...	...	48·7		51	...	...	21·04	
1835·50	...	...	...	...	46·8		173	...	...	25·22	
1836·50	...	...	...	...	45·7		272	...	...	33·03	
1837·50	47·26	46·65	46·26	46·08	45·7		333	1837·2	...	26·77	
1838·50	46·94	46·16	45·39	44·81	44·7		282	...	...	31·04	
1839·50	46·69	46·15	45·67	45·33	46·4		162	...	...	23·45	
1840·50	46·77	46·44	46·02	45·68	46·7		152	...	...	25·50	
1841·50	46·78	46·48	46·06	45·70	46·6		102	...	...	26·22	
1842·59	46·88	46·81	46·78	46·85	48·0		68	...	...	16·87	
1843·50	47·14	46·92	46·49	46·18	47·6		34	...	...	23·80	
1844·50	47·21	47·11	46·83	46·44	46·7		52	...	1844·0	20·94	
1845·40	47·06	46·56	45·97	45·57	46·3		114	...	...	26·62	
1846·50	47·29	47·60	47·76	47·78	49·6		157	...	...	31·54	
1847·50	47·59	47·33	46·88	46·60	47·4		257	...	...	22·77	
1848·50	47·38	46·97	46·42	46·02	47·0		330	1848·6	...	30·60	
1849·50	47·25	46·86	46·61	46·52	46·5		238	...	...	22·21	...
1850·50	47·24	47·00	46·69	46·49	47·0	...	186	...	...	...	...
1851·50	47·40	47·26	47·02	46·80	...	...	151	...	...	...	...
1852·50	47·55	47·48	47·28	47·05	...	...	125	...	...	...	...
1853·50	47·48	47·03	46·50	46·10	...	...	91	...	...	...	...
1854·50	47·41	47·18	46·92	46·75	...	...	67	...	...	...	...
1855·50	47·30	46·79	46·22	45·78	These numbers are only comparable *inter se.*	...	79	...	...	...	...
1856·50	47·14	46·67	46·34	46·11		45·7	34	...	1856·2	...	33·00
1857·50	47·30	47·34	47·42	47·54		48·0	98	...	...	...	30·56
1858·50	47·86	47·98	47·71	47·34		46·6	188	...	...	Only comparable *inter se.*	33·91
1859·50	47·85	47·64	47·26	46·90		46·8	205	...	...		37·17
1860·50	47·36	46·43	45·62	45·14		44·5	211	1860·5	...		37·88
1861·50	47·12	...	46·50	46·34		46·9	204	...	...		45·07
1862·50	47·20	...	46·30	45·96		46·1	160	...	...		45·29
1863·50	47·20	...	46·74	46·67		46·8	124	...	...		42·11
1864·50	47·16	...	46·25	45·84		45·5	115	...	...		38·58
1865·50	47·08	...	46·50	46·41		46·9	93	...	...		33·91
1866·50	47·30	...	46·65	46·22		46·3	45	...	...		41·41
1867·50	47·14	...	46·18	45·82		45·7	15	...	1867·0		38·52
1868·50	47·34	...	47·31	47·37		47·6	75	...	...		43·03
1869·50	47·55	...	47·11	46·92		46·4	148	...	...		36·54
1870·50	47·37	...	46·54	46·16		46·1	278	1870·9	...	...	31·81
1871·50	47·32	...	46·52	46·24		46·4	222	...	...	...	37·19
1872·50	47·36	...	46·73	46·50		46·9	203	...	...	...	54·15
1873·50	47·28	...	46·38	46·08		46·4	133	...	...	...	39·33
1874·50	47·38	...	47·09	46·80		46·5	89	...	...	...	40·17
1875·50	47·36	...	46·59	46·41	...	46·9	34	...	...	...	39·08
1876·50	47·24	...	46·30	45·96	...	46·6	23	...	1876·8 (1877·5)	...	44·88
1877·50	...	...	...	...	...	45·7	...	...	Since proved by British Obs. to be 1879·0.	...	51·83
1878·50	...	...	...	...	...	46·8	...	...		...	36·28
1879·50	...	...	...	...	...	43·9	...	...		...	36·43

TABLE II.—*Quadruple Annual Mean Temperatures for Four several Sub-Annual Epochs.*

(See Plate XV.)

Date.	t_1 or 25·6 ft. deep Therm.	t_2 or 12·8 ft. deep Therm.	t_3 or 6·4 ft. deep Therm.	t_4 or 3·2 ft. deep Therm.
	° F.	° F.	° F.	° F.
1837·0	...	...	...	...
·25	...	...	...	...
·50	47·26	46·65	46·26	46·08
·75	47·18	46·62	45·94	45·40
1838·0	47·12	46·55	45·94	45·40
·25	47·04	46·36	45·58	44·99
·50	46·94	46·16	45·39	44·82
·75	46·82	46·07	45·43	45·02
1839·0	46·75	46·08	45·52	45·16
·25	46·72	46·13	45·60	45·21
·50	46·69	46·16	45·67	45·34
·75	46·68	46·21	45·81	45·58
1840·0	46·70	46·39	46·14	45·94
·25	46·75	46·44	46·09	45·82
·50	46·77	46·44	46·02	45·68
·75	46·77	46·38	45·88	45·54
1841·0	46·76	46·41	46·00	45·66
·25	46·76	46·44	46·03	45·73
·50	46·78	46·48	46·08	45·70
·75	46·79	46·48	46·12	45·79
1842·0	46·80	46·48	46·16	45·99
·25	46·82	46·62	46·52	46·49
·50	46·88	46·81	46·78	46·84
·75	46·99	47·08	47·06	46·98
1843·0	47·10	47·12	46·79	46·41
·25	47·15	46·99	46·58	46·27
·50	47·14	46·92	46·48	46·18
·75	47·13	46·92	46·52	46·20
1844·0	47·13	46·97	46·82	46·74
·25	47·17	47·10	46·85	46·54
·50	47·21	47·11	46·82	46·44
·75	47·23	46·97	46·52	46·13
1845·0	47·20	46·83	46·25	45·74
·25	47·13	46·68	46·04	45·52
·50	47·06	46·56	45·98	45·57
·75	47·01	46·64	46·39	46·32
1846·0	47·03	46·85	46·71	46·69
·25	47·12	47·19	47·32	47·49
·50	47·29	47·60	47·76	47·78
·75	47·48	47·74	47·54	47·24
1847·0	47·60	47·70	47·37	46·92
·25	47·64	47·56	47·08	46·57
·50	47·59	47·33	46·88	46·60
·75	47·52	47·21	46·82	46·58
1848·0	47·46	47·16	46·84	46·68
·25	47·42	47·09	46·66	46·40
·50	47·38	46·97	46·42	46·02
·75	47·31	46·93	46·59	46·47
1849·0	47·28	46·95	46·56	46·33
·25	47·27	46·88	46·53	46·34
·50	47·25	46·86	46·61	46·52
·75	47·24	46·82	46·47	46·26
1850·0	47·23	46·83	46·52	46 33
·25	47·22	46·91	46·66	46·49
·50	47·24	47·00	46·69	46·49
·75	47·28	47·15	46·99	46·82
1851·0	47·34	47·22	46·97	46·75
·25	47·38	47·21	46·91	46·66
·50	47·40	47·26	47·02	46·80
·75	47·44	47·28	46·98	46·69
1852·0	47·46	47·32	47·09	46·82
·25	47·49	47·42	47·32	47·20
·50	47·55	47·48	47·28	47·05
·75	47·59	47·43	47·02	46·60
1853·0	47·59	47·25	46·79	46·47
·25	47·54	47·14	46·56	46·10
·50	47·48	47·03	46·50	46·10
·75	47·41	46·92	46·47	46·28
1854·0	47·38	47·06	46·74	46·56
·25	47·39	47·10	46·84	46·74
·50	47·41	47·18	46·92	46·75
·75	47·45	47·25	46·85	46·42
1855·0	47·44	47·01	46·38	45·85
·25	47·37	46·89	46·35	45·95
·50	47·30	46·79	46·22	45·78
·75	47·23	46·68	46·25	46·07
1856·0	47·19	46·78	46·44	46·22
·25	47·18	46·72	46·26	45·79
·50	47·14	46·67	46·34	46·11
·75	47·13	46·79	46·55	46·30
1857·0	47·15	46·85	46·64	46·48
·25	47·20	47·05	46·96	46·98
·50	47·30	47·34	47·42	47·54
·75	47·43	47·67	47·74	47·73
1858·0	47·59	47·88	48·05	48·14
·25	47·75	48·05	48·10	48·06
·50	47·86	47·98	47·71	47·34
·75	47·88	47·77	47·56	47·44
1859·0	47·87	47·76	47·49	47·21
·25	47·86	47·70	47·42	47·19
·50	47·85	47·64	47·26	46·90
·75	47·82	47·38	46·64	46·00
1860·0	47·71	47·02	46·18	45·58
·25	47·54	46·71	45·81	45·20
·50	47·36	46·43	45·62	45·14
·75	47·20	...	45·80	45·52
1861·0	47·10	...	46·05	45·85
·25	47·09	...	46·23	46·03
·50	47·12	...	46·50	46·34
·75	47·17	...	46·68	46·48
1862·0	47·22	...	46·68	46·41
·25	47·23	...	46·43	46·09
·50	47·20	...	46·30	45·96
·75	47·16	...	46·38	46·17
1863·0	47·14	...	46·60	46·26
·25	47·17	...	46·79	46·45
·50	47·20	...	46·85	46·67
·75	47·23	...	46.69	46·17
1864·0	47·22	...	46·44	46·12
·25	47·19	...	46·31	46·00
·50	47·16	...	46·25	45·84
·75	47·13	...	46·06	45·69
1865·0	47·09	...	45·96	45·67
·25	47·06	...	46·27	46·19
·50	47·08	...	46·50	46·41
·75	47·15	...	46·89	46·82
1866·0	47·23	...	46·93	46·70
·25	47·30	...	46·76	46·33
·50	47·30	...	46·65	46·22
·75	47·28	...	46·44	46·01
1867·0	47·24	...	46·33	45·88
·25	47·13	...	46·24	45·87
·50	47·14	...	46·18	45·82
·75	47·10	...	46·34	46·30
1868·0	47·11	...	46·81	46·89
·25	47·21	...	47·25	47·40
·50	47·34	...	47·31	47·37
·75	47·45	...	47·48	47·39
1869·0	47·54	...	47·26	47·06
·25	47·56	...	47·03	46·88
·50	47·55	...	47·11	46·92
·75	47·53	...	46·66	46·28
1870·0	47·46	...	46·63	46·34
·25	47·40	...	46·66	46·29
·50	47·37	...	46·54	46·16
·75	47·34	...	46·59	46·40
1871·0	47·33	...	46·62	46·34
·25	47·33	...	46·58	46·30
·50	47·32	...	46·52	46·24
·75	47·31	...	46·82	46·68
1872·0	47·33	...	46·80	46·54
·25	47·34	...	46·78	46·49
·50	47·36	...	46·73	46·50
·75	47·36	...	46·56	46·10
1873·0	47·35	...	46·48	46·17
·25	47·32	...	46·42	46·00
·50	47·28	...	46·38	46·08
·75	47·24	...	46·60	46·45
1874·0	47·25	...	46·85	46·70
·25	47·31	...	46·96	46·85
·50	47·38	...	47·09	46·80
·75	47·44	...	46·76	46·33
1875·0	47·43	...	46·71	46·38
·25	47·40	...	46·63	46·36
·50	47·36	...	46·59	46·41
·75	47·34	...	46·71	46·54
1876·0	47·32	...	46·41	46·10
·25	47·27	...	46·39	46·06
·50	47·24	...	46·30	45·96
·75	...	...	...	...

TABLE III.—*Mean Temperature of Air of Scottish Country and Town Stations, by the Meteorological Society of Scotland.*

QUADRUPLE ANNUAL MEANS FOR QUARTERLY PERIODS.

Date.	Q. Ann. Mean Temp. of Air.	Date.	Q. Ann. Mean Temp. of Air.	Date.	Q. Ann. Mean Temp. of Air.	Date.	Q. Ann. Mean Temp. of Air.
	° F.		° F.		° F.		° F.
1856·50	45·7	...	...	...	...	...	...
1856·75	45·8	...	...	...	...	...	...
1857·0	46·2	1863·0	46·6	1869·0	46·8	1875·0	46·2
1857·25	47·0	1863·25	46·5	1869·25	46·6	1875·25	46·4
1857·50	48·0	1863·50	46·9	1869·50	46·4	1875·50	46·9
1857·75	48·1	1863·75	45·6	1869·75	45·6	1875·75	46·7
1858·0	48·2	1864·0	45·8	1870·0	46·3	1876·0	46·3
1858·25	47·8	1864·25	45·9	1870·25	46·5	1876·25	46·2
1858·50	46·6	1864·50	45·5	1870·50	46·2	1876·50	46·6
1858·75	47·3	1864·75	45·4	1870·75	46·7	1876·75	46·8
1859·0	47·2	1865·0	45·8	1871·0	46·1	1877·0	46·4
1859·25	47·2	1865·25	46·6	1871·25	45·9	1877·25	45·9
1859·50	46·8	1865·50	46·9	1871·50	46·4	1877·50	45·7
1859·75	45·6	1865·75	47·6	1871·75	46·8	1877·75	46·0
1860·0	45·1	1866·0	47·0	1872·0	46·9	1878·0	46·8
1860·25	44·5	1866·25	46·3	1872·25	46·8	1878·25	47·6
1860·50	44·5	1866·50	46·3	1872·50	46·9	1878·50	46·8
1860·75	45·2	1866·75	45·9	1872·75	46·2	1878·75	45·3
1861·0	45·8	1867·0	45·8	1873·0	46·2	1879·0	44·4
1861·25	46·3	1867·25	46·0	1873·25	46·1	1879·25	43·6
1861·50	46·9	1867·50	45·8	1873·50	46·4	1879·50	43.9
1861·75	46·8	1867·75	46·8	1873·75	47·0	1879·75	45·3
1862·0	46·6	1868·0	47·3	1874·0	47·1	1880·0	46·5
1862·25	46·2	1868·25	47·8	1874·25	47·3	1880·25	46·7
1862·50	46·2	1868·50	47·6	1874·50	46·5	...	...
1862·75	46·7	1868·75	47·5	1874·75	45·9	...	...

TABLE IV.—*Rainfall in Inches, of Scottish Country and Town Stations, per the Meteorological Society of Scotland.*

QUADRUPLE ANNUAL SUMS FOR QUARTERLY PERIODS.

Date.	Q. Ann. Sum of Rainfall.	Date.	Q. Ann. Sum of Rainfall.	Date.	Q. Ann. Sum of Rainfall.	Date.	Q. Ann. Sum of Rainfall.
	Inches.		Inches.		Inches.		Inches.
1856·50	33·00	...	...	...	...	...	...
1856·75	34·32	...	...	...	...	...	...
1857·0	32·40	1863·0	43·08	1869·0	37·32	1875·0	41·76
1857·25	29·64	1863·25	43·44	1869·25	36·96	1875·25	39·12
1857·50	30·60	1863·50	42·12	1869·50	36·48	1875·50	39·12
1857·75	29·40	1863·75	42·00	1869·75	34·56	1875·75	42·24
1858·0	29·52	1864·0	39·24	1870·0	35·04	1876·0	42·84
1858·25	31·44	1864·25	37·92	1870·25	33·00	1876·25	42·24
1858·50	33·84	1864·50	38·64	1870·50	31·80	1876·50	44·88
1858·75	39·60	1864·75	36·72	1870·75	33·24	1876·75	46·32
1859·0	38·16	1865·0	35·64	1871·0	34·32	1877·0	48·48
1859·25	36·60	1865·25	35·16	1871·25	37·32	1877·25	51·84
1859·50	37·20	1865·50	33·96	1871·50	37·20	1877·50	51·84
1859·75	36·24	1865·75	38·16	1871·75	41·52	1877·75	46·20
1860·0	38·40	1866·0	38·04	1872·0	44·88	1878·0	44·64
1860·25	37·68	1866·25	41·40	1872·25	48·72	1878·25	41·52
1860·50	37·92	1866·50	41·40	1872·50	54·12	1878·50	36·24
1860·75	38·64	1866·75	38·52	1872·75	49·20	1878·75	35·76
1861·0	35·88	1867·0	42·96	1873·0	43·80	1879·0	36·36
1861·25	44·04	1867·25	41·88	1873·25	43·44	1879·25	40·20
1861·50	45·12	1867·50	38·52	1873·50	39·36	1879·50	36·48
1861·75	44·40	1867·75	42·96	1873·75	38·76	1879·75	37·20
1862·0	50·28	1868·0	40·56	1874·0	39·12	...	...
1862·25	44·28	1868·25	39·36	1874·25	38·88	...	...
1862·50	45·24	1868·50	42·96	1874·50	40·20	...	...
1862·75	45·12	1868·75	38·76	1874·75	40·68	...	...

TABLE V.—*Edinburgh Air Temperatures, observed by Alex. Adie, discussed by Prof. J. D. Forbes, in the Transactions of Royal Society, Edinburgh,* Vol. xxii., 1860.

QUARTERLY MEANS, AND ALSO ANNUAL MEANS, SPECIALLY TAKEN AT EVERY QUARTER.

Date.	Quarterly.	Annual.
1821·00		
·125	39·6	
·25		
·375	48·8	
·50		47·4
·625	57·0	
·75		47·8
·875	44·4	
1822·00		48·7
·125	41·1	
·25		48·2
·375	52·4	
·50		47·8
·625	55·1	
·75		46·4
·875	42·6	
1823·00		45·5
·125	35·3	
·25		45·4
·375	49·0	
·50		45·3
·625	54·6	
·75		46·3
·875	42·2	
1824·00		46·7
·125	39·5	
·25		47·4
·375	50·6	
·50		47·2
·625	57·2	
·75		47·3
·875	41·6	
1825·00		47·5
·125	39·8	
·25		48·0
·375	51·3	
·50		48·2
·625	59·5	
·75		48·0
·875	42·2	
1826·00		48·5
·125	39·0	
·25		48·4
·375	53·3	
·50		48·7
·625	59·2	
·75		48·1
·875	43·3	
1827·00		47·4
·125	36·5	
·25		46·7
·375	50·7	
·50		47·1
·625	56·2	
·75		48·2
·875	45·0	
1828·00		48·3
·125	40·8	
·25		48·3
·375	51·1	
·50		48·5
·625	56·4	
·75		47·5
·875	45·6	
1829·00		47·2
·125	36·9	
·25		46·5
·375	50·0	
·50		45·2
·625	53·6	
·75		45·6
·875	40·5	
1830·00		45·4
·125	38·2	
·25		45·6
·375	49·4	
·50		46·0
·625	54·2	
·75		46·1
·875	42·1	
1831·00		45·7
·125	38·6	
·25		46·8
·375	48·0	
·50		47·5
·625	58·3	
·75		48·0
·875	45·1	
1832·00		48·5
·125	40·5	
·25		48·0
·375	50·1	
·50		47·7
·625	56·4	
·75		47·0
·875	43·9	
1833·00		47·5
·125	37·7	
·25		47·2
·375	51·9	
·50		47·2
·625	55·5	
·75		48·2
·875	43·7	
1834·00		48·0
·125	41·6	
·25		48·5
·375	51·4	
·50		48·7
·625	57·2	
·75		48·2
·875	44·7	
1835·00		47·6
·125	39·4	
·25		47·4
·375	49·3	
·50		46·8
·625	56·3	
·75		46·6
·875	42·3	
1836·00		46·7
·125	38·3	
·25		46·0
·375	49·9	
·50		45·8
·625	53·5	
·75		45·2
·875	41·3	
1837·00		44·6
·125	36·2	
·25		45·2
·375	47·6	
·50		45·7
·625	55·6	
·75		45·0
·875	43·4	
1838·00		44·8
·125	33·2	
·25		45·1
·375	47·2	
·50		44·7
·625	56·5	
·75		45·7
·875	41·9	
1839·00		46·3
·125	37·2	
·25		46·2
·375	49·5	
·50		46·3
·625	56·2	
·75		46·9
·875	42·6	
1840·00		47·2
·125	39·3	
·25		47·0
·375	50·6	
·50		46·7
·625	55·5	
·75		46·7
·875	41·5	
1841·00		46·7
·125	39·3	
·25		46·8
·375	50·4	
·50		46·6
·625	56·0	
·75		46·6
·875	40·8	
1842·00		46·9
·125	39·2	
·25		47·2
·375	51·6	
·50		48·0
·625	57·1	
·75		47·8
·875	44·0	
1843·00		47·0
·125	38·7	
·25		47·2
·375	48·3	
·50		47·6
·625	57·9	
·75		47·8
·875	45·6	
1844·00		48·6
·125	39·5	
·25		47·9
·375	51·2	
·50		46·8
·625	55·2	
·75		45·9
·875	41·1	
1845·00		45·6
·125	36·2	
·25		45·6
·375	50·0	
·50		46·3
·625	55·0	
·75		48·0
·875	43·9	
1846·00		48·8
·125	43·2	
·25		49·9
·375	53·2	
·50		49·6
·625	59·5	
·75		48·3
·875	42·5	
1847·00		47·5
·125	37·9	
·25		46·8
·375	50·0	
·50		47·4
·625	57·0	
·75		47·6
·875	44·8	
1848·00		47·9
·125	38·4	
·25		47·6
·375	51·5	
·50		47·0
·625	55·7	
·75		47·6
·875	42·4	
1849·00		46·9
·125	40·7	
·25		46·8
·375	48·9	
·50		46·5
·625	55·4	
·75		46·0
·875	41·1	
1850·00		46·5
·125	38·6	
·25		46·7
·375	51·0	
·50		47·0
·625	56·1	
·75		
·875	42·4	

TABLE VI.—*Edinburgh Rainfalls, observed by Alexander Adie, discussed by Professor J. D. Forbes, in the Transactions of Royal Society, Edinburgh,* Vol. xxii., 1860.

QUARTERLY MONTHLY MEANS, AND ALSO ANNUAL MONTHLY MEANS AND ANNUAL SUMS, SPECIALLY TAKEN AT EVERY QUARTER.

Date.	Quarterly.	Annual	
1822·00			
·125	2·43		
·25			
·375	1·52		
·50		2·18	26·16
·625	2·72		
·75		2·13	25·56
·875	2·04		
1823·00		2·17	26·04
·125	2·25		
·25		2·32	27·84
·375	1·68		
·50		2·52	30·24
·625	3·31		
·75		2·28	27·36
·875	2·85		
1824·00		2·13	25·56
·125	1·30		
·25		1·70	20·40
·375	1·07		
·50		2·07	24·84
·625	1·57		
·75		1·94	23·28
·875	4·33		
1825·00		2·24	26·88
·125	0·81		
·25		2·25	27·00
·375	2·24		
·50		1·84	22·08
·625	1·63		
·75		1·95	23·40
·875	2·70		
1826·00		1·64	19·68
·125	1·22		
·25		1·66	19·92
·375	1·02		
·50		1·27	15·24
·625	1·72		
·75		1·78	21·36
·875	1·13		
1827·00		2·00	23·88
·125	3·25		
·25		2·26	27·12
·375	1·88		
·50		2·72	32·64
·625	2·77		
·75		2·22	26·64
·875	2·96		
1828·00		2·09	25·08
·125	1·29		
·25		2·26	26·88
·375	1·36		
·50		2·10	25·20
·625	3·44		
·75		2·15	25·80
·875	2·33		

Date.	Quarterly.	Annual	
1829·00		2·32	27·84
·125	1·47		
·25		2·55	30·60
·375	2·05		
·50		2·49	29·88
·625	4·35		
·75		2·46	29·52
·875	2·11		
1830·00		2·51	30·12
·125	1·31		
·25		2·83	33·96
·375	2·26		
·50		2·77	33·24
·625	5·63		
·75		2·98	35·76
·875	1·88		
1831·00		2·72	32·64
·125	2·17		
·25		1·98	23·76
·375	1·21		
·50		2·04	24·48
·625	2·67		
·75		1·78	21·36
·875	2·12		
1832·00		1·93	23·16
·125	1·11		
·25		1·74	20·88
·375	1·82		
·50		1·94	23·28
·625	1·90		
·75		2·04	24·48
·875	2·92		
1833·00		2·05	24·60
·125	1·51		
·25		2·00	24·00
·375	1·87		
·50		1·74	20·88
·625	1·69		
·75		1·84	22·08
·875	1·89		
1834·00		1·58	18·96
·125	1·93		
·25		1·90	22·80
·375	0·80		
·50		1·75	21·00
·625	2·96		
·75		1·76	21·12
·875	1·32		
1835·00		1·88	22·56
·125	1·95		
·25		1·87	22·44
·375	1·28		
·50		2·10	25·20
·625	2·93		
·75		2·40	28·80
·875	2·25		

Date.	Quarterly.	Annual	
1836·00		2·47	29·64
·125	3·16		
·25		2·72	32·64
·375	1·53		
·50		2·75	33·00
·625	3·93		
·75		2·35	28·20
·875	2·39		
1837·00		2·47	29·64
·125	1·55		
·25		2·35	28·20
·375	2·00		
·50		2·23	26·76
·625	3·47		
·75		2·38	28·56
·875	1·91		
1838·00		2·70	32·40
·125	2·15		
·25		2·62	31·44
·375	3·28		
·50		2·59	31·08
·625	3·14		
·75		2·44	29·28
·875	1·78		
1839·00		2·01	24·12
·125	1·56		
·25		1·92	23·04
·375	1·57		
·50		1·96	23·52
·625	2·79		
·75		2·04	24·48
·875	1·90		
1840·00		2·22	26·64
·125	1·91		
·25		2·18	26·16
·375	2·30		
·50		2·12	25·44
·625	2·61		
·75		1·94	23·28
·875	1·67		
1841·00		1·68	20·16
·125	1·16		
·25		1·87	22·44
·375	1·28		
·50		2·18	26·16
·625	3·38		
·75		2·36	28·32
·875	2·92		
1842·00		2·25	27·00
·125	1·85		
·25		1·77	21·24
·375	0·86		
·50		1·41	16·92
·625	1·45		
·75		1·28	15·36
·875	1·47		

Date.	Quarterly.	Annual	
1843·00		1·66	19·92
·125	1·35		
·25		1·79	21·48
·375	2·37		
·50		1·98	23·76
·625	1·96		
·75		2·09	25·08
·875	2·25		
1844·00		1·77	21·24
·125	1·79		
·25		1·88	22·56
·375	1·09		
·50		1·74	20·88
·625	2·40		
·75		1·64	19·68
·875	1·70		
1845·00		1·84	22·08
·125	1·35		
·25		1·82	21·84
·375	1·91		
·50		2·22	26·61
·625	2·32		
·75		2·32	27·84
·875	3·29		
1846·00		2·48	29·76
·125	1·74		
·25		2·95	35·40
·375	2·58		
·50		2·63	31·56
·625	4·18		
·25		2·32	27·84
·875	2·02		
1847·00		2·32	27·84
·125	0·48		
·25		1·57	18·84
·375	2·60		
·50		1·90	22·80
·625	1·18		
·75		2·55	30·60
·875	3·33		
1848·00		2·54	30·48
·125	3·09		
·25		2·65	31·80
·375	2·57		
·50		2·55	30·60
·625	1·60		
·75		2·18	26·16
·875	2·94		
1849·00		2·02	24·24
·125	1·62		
·25		2·20	26·40
·375	1·92		
·50		1·85	22·20
·625	2·30		
·75		1·83	21·96
·875	1·56		
1850·00		1·78	21·36
·125	1·53		
·25	1·73	1·68	20·16
·50	1·89		

TABLE VII.—*Rainfall at Culloden, from Scottish Meteorological Society's Journal,* July 1873.

QUADRUPLE ANNUAL SUMS, CHIEFLY TO FILL THE GAP BETWEEN THE LAST OF A. ADIE'S OBSERVATIONS, AND THE FIRST OF THE METEOROLOGICAL SOCIETY.

Date.	Quarterly.	Annual.	Annual Sums.	Date.	Quarterly.	Annual.	Annual Sums.	Date.	Quarterly.	Annual.	Annual Sums.
1841·00				1848·00		2·14	25·68	1855·00		2·07	24·84
·125	1·19			·125	2·26			·125	1·72		
·25				·25		2·02	24·24	·25		2·16	25·92
·375	1·64			·375	2·08			·375	1·26		
·50		2·44	29·28	·50		2·06	24·72	·50		1·75	21·00
·625	3·21			·625	1·51			·625	2·61		
·75		2·59	31·08	·75		2·06	24·72	·75		1·70	20·40
·875	3·70			·875	2·40			·875	1·39		
1842·00		2·46	29·52	1849·00		1·85	22·20	1856·00		2·09	25·08
·125	1·78			·125	2·27			·125	1·53		
·25		2·26	27·12	·25		2·21	26·52	·25		2·20	26·40
·375	1·13			·375	1·22			·375	2·82		
·50		1·97	23·64	·50		1·93	23·16	·50		2·18	26·16
·625	2·43			·625	2·96			·625	3·05		
·75		1·83	21·96	·75		1·74	20·88	·75		2·14	25·68
·875	2·55			·875	1·26			·875	1·30		
1843·00		1·95	23·40	1850·00		1·76	21·12	1857·00		1·80	21·60
·125	1·22			·125	1·54			·125	1·37		
·25		1·90	22·80	·25		1·53	18·36	·25		1·66	19·92
·375	1·60			·375	1·28			·375	1·47		
·50		1·90	22·80	·50		1·91	22·92	·50		1·82	21·84
·625	2·23			·625	2·05			·625	2·48		
·75		2·16	25·92	·75		1·89	22·68	·75		1·88	22·56
·875	2·56			·875	2·77			·875	1·96		
1844·00		2·00	24·00	1851·00		1·82	21·84	1858·00		1·99	23·88
·125	2·23			·125	1·48			·125	1·61		
·25		2·17	26·04	·25		1·62	19·44	·25		2·06	24·72
·375	1·00			·375	0·96			·375	1·91		
·50		1·98	23·76	·50		1·24	14·88	·50		2·07	24·84
·625	2·88			·625	1·29			·625	2·75		
·75		1·81	21·72	·75		1·45	17·40	·75		2·30	27·60
·875	1·82			·875	1·23			·875	2·00		
1845·00		1·95	23·40	1852·00		1·46	17·52	1859·00		2·12	25·44
·125	1·55			·125	2·32			·125	2·56		
·25		1·92	23·04	·25		1·72	20·64	·25		1·91	22·92
·375	1·54			·375	1·01			·375	1·19		
·50		2·30	27·60	·50		2·20	26·40	·50		2·17	26·04
·625	2·75			·625	2·34			·625	1·90		
·75		2·28	27·36	·75		1·97	23·44	·75		2·00	24·00
·875	3·37			·875	3·14			·875	3·04		
1846·00		2·53	30·36	1853·00		2·08	24·96	1860·00		2·10	25·20
·125	1·45			·125	1·38			·125	1·89		
·25		2·51	30·12	·25		2·02	24·24	·25		2·12	25·44
·375	2·54			·375	1·47			·375	1·56		
·50		2·36	28·32	·50		1·66	19·92	·50		1·79	21·48
·625	2·68			·625	2·09			·625	1·99		
·75		2·15	25·80	·75		1·56	18·72	·75		1·72	20·64
·875	2·77			·875	1·72			·875	1·73		
1847·00		2·17	26·04	1854·00		1·55	18·60	1861·00		1·74	20·88
·125	0·62			·125	0·97			·125	1·58		
·25		2·00	24·00	·25		1·58	18·96	·25		2·35	28·20
·375	2·62			·375	1·41			·375	1·68		
·50		1·86	22·32	·50		1·92	23·04	·50		2·62	31·44
·625	1·99			·625	2·24			·625	4·41		
·75		2·27	27·24	·75		2·11	25·32	·75		2·60	31·20
·875	2·21			·875	3·07			865	2·80		
								1862·00		2·73	32·76
								·125	1·53		
								·25		2·15	25·80
								·375	2·17		
								50		2·06	24·72
								·625	2·09		
								·75			
								·875	2·43		

XXIII.—*Note on a Theorem in Geometry of Position.* By Professor TAIT.

(Plate XVI.)

(Read July 19; revised November 13, 1880.)

In connection with the problem of Map-colouring, I incidentally gave (Proc. R.S.E. 1880, p. 502) a theorem which may be stated as follows:—

If 2n *points be joined by* 3n *lines, so that three lines, and three only, meet at each point, these lines can be divided (usually in many different ways) into three groups of* n *each, such that one of each group ends at each of the points.*

Fig. 1, Plate XVI., shows such an arrangement (drawn at random) with *one* mode of grouping the lines, indicated by the marks **O, I, II.**

The difficulty of obtaining a simple proof of this theorem originates in the fact that it is not true without limitation. For it fails when an odd number of the points forms a group connected by a *single* line only with the rest, as in fig. 2; and, though we may enunciate the theorem in a form in which it is universally true so far as the literal interpretation of the words is concerned, we do not, so far as I can see, thereby facilitate the proof: while we deprive the theorem of its full generality. For the projection of a polyhedron cannot have a group of points joined to the rest by *two* lines only; and yet the theorem is true for such a diagram. The altered form is as follows:—

The edges of any polyhedron, which has trihedral summits only, can be divided into three groups, one from each group ending in each summit.

But a diagram such as fig. 3, for which the proposition is obviously true, is excluded from this enunciation, unless we agree to apply the term polyhedron to solids such as (for instance) an ordinary cylindrical lens with two edges and flat ends.

HAMILTON's *Icosian Game* is a particular application of this theorem, the corresponding figure being a projection of a pentagonal dodecahedron. It was suggested to him by the remark, in Mr KIRKMAN's paper on Polyhedra (Phil. Trans. 1858, p. 160), that a clear "circle of edges" of a unique type passed through all the summits of this polyhedron.

In this note I sketch, each very briefly, a number of different ways of considering the question.

1. The simplest mode is to join, two and two, in any way whatever, the points of the system, by lines additional to those already drawn, neglecting any new intersections which may thus arise. The figure has then an even

number of points, with four lines drawn to each; and can therefore be regarded as formed of superposed (not self-cutting) closed circuits, each of which cuts another in an even number of points. The new lines must be so grouped that in the circuits which contain them they *alternate* with lines originally in the figure. It will be seen in § 2 that this proves the theorem at once by the help of those circuits which contain none of the new lines. But the application of this method to particular cases is by no means easy; for we may have to try several combinations before we obtain a solution of the kind desired.

2. Assuming, for a moment, the truth of the proposition as given in the first statement, it is obvious that the lines of any two of the groups together form a *closed* polygon or polygons, each of an *even* number of sides: and, conversely, when (as just shown) we have such circuits, the proposition is true. (The italicised words show at once the reason for the exception to the theorem. For if the single joining line be part of a polygon, *that* cannot be a closed one; and, if it be not part of a polygon, there must be at least two polygons with an odd number of sides each.) When there are more polygons than one, the letterings of the alternate sides of one of them may be interchanged; and we thus get, by combining these separately with the third set of n lines, a couple of new solutions. If either of these consist of more polygons than one, this process may be again applied, and thus we have two more solutions. Hence it is always possible to obtain a solution in which two assigned sides of one compartment of the diagram shall form parts of the same even-sided polygon. (From this consideration, as appears in § 5, we have another direct proof of the theorem.) Hence, also, it would appear that, as this breaking into different sets of polygons cannot go on indefinitely, there must always be at least one solution which consists of a single polygon: provided, at least, that we keep to projections of polyhedra, for the statement is obviously not true of diagrams like fig. 3. But on this point I am not yet certain; and I pass it by for the present, as it is not of importance to the proposition, though it would be of great consequence to the making a perfectly general puzzle on the plan of the icosian game.

3. A glance at the groups of connected figures of Plate XVI. (in which the polygon or polygons are bounded by double lines), will show better than any words of description the nature of the processes which I have just indicated.

Fig. 7 has a very large number of solutions, twelve only of which are drawn.
„ 8 is merely fig. 1 a little distorted. The additional line, which distinguishes it from fig. 7, makes it essentially unsymmetrical.
„ 9 is essentially the same diagram as that of the *Icosian Game.*
„ 10 is merely fig. 3; with one additional line, causing one at least of the two-sided compartments to be joined to the rest by three lines This at once makes the solution with a single polygon possible.

N.B.—When a figure is symmetrical about any axis, the perversion of any solution is also a solution.

4. Or thus: when a set of points are joined so that two, and only two, joining lines meet at each point, these lines must obviously form one or more closed polygons. Hence, in the case before us, by limiting the selection to two out of the three lines drawn to each point, we can always, in many different ways, form a polygon or polygons. If the number of sides in each of these is even, the main proposition is at once proved; for the alternate sides of the polygons belong to two of the three groups—the unused lines forming the third group. Such solutions must evidently be possible in all cases, with the exception of that already excluded. This knowledge, however, does not at once help us to a *practical* solution of the problem in any particular case. We must, therefore, look at the result more generally.

If the selection we have made gives more than one polygon, two or other even number of them may have an odd number of sides each. Suppose there are but two. If these be connected by *one* line only, we have the excepted case above. If they be connected by three, or a larger *odd* number of lines, we may always proceed as is indicated in figs. 6. 6*a* shows the two odd-sided polygons. 6*b* and 6*c* show how, neglecting the points C and C′, we form even-sided polygons passing through them and including AB and A′B′ respectively. Finally, 6*d* shows the result when the two latter figures are joined. Thus the proposition is proved by actually effecting the decomposition into polygons of an even number of sides. Hence it is true for any even number of points (the excepted case excluded) if it is true for smaller even numbers of points. But it is obviously true for two, for four, and for six, points.

5. Another mode of reaching the same conclusion, is to pass from a case of $2n$ points to one of $2n+2$ by drawing a new line terminating in any two sides of one of the even-sided polygons of the former case (§ 2). That polygon remains even-sided, but its sides must be relettered; and then we have one or more solutions of the new case.

In fact, by temporarily suppressing, two by two, points and their joining line (always taking care that the figure left shall not belong to the excepted case) we can reduce any case, however complex, to the four points for which the proposition is always true. [Or we may suppress one line, and divide the figure into two odd-sided polygons passing respectively through its ends. On restoring the line, these two polygons give a solution.]

6. Practically, in every case, the simplest mode of solution is to begin at any point, and go through all (through some, perhaps, more than once) till we return to the starting-point. Then treat, as not gone over, all the lines which have been gone over an even number of times. This process is very easily learned by trial, the only special rule to be attended to being that we must never isolate a point. Should two odd-sided polygons be thus obtained, we may either begin afresh:—or go over a second time, attending to the above

rule, part of the region of the figure in which these two polygons are contained. It is easy to see the connection of this method with the idea of a galvanic circuit of unit strength circulating (say right-handedly) in each of the polygons:—and the treating of any new or unused line as a conductor which can, when necessary, be split into two traversed by equal and opposite currents. It is probable that the known laws of such currents in a network may lead to the proof of the existence of a single polygon when the figure is a projection of a polyhedron.

7. Another method is suggested by Mr KEMPE'S solution of the map-colouring problem (*Nature*, vol. xxi. p. 399). As the number of districts is, necessarily, $n+2$, and the aggregate number of their sides $6n$, there must always be at least one district with fewer than six sides. Now, one side may be erased from a district of two or of three sides, and restored again, without altering the nomenclature of the remaining lines. Similarly, either pair of opposite sides of a four-sided district may be erased, and afterwards restored. But when we erase any two non-adjacent sides of a five-sided district, a condition is thereby imposed on the nomenclature of the remaining lines, with which I do not yet see how generally to deal.

8. An immediate consequence of the theorem is that, in any network of *triangles* (however many lines meet at a point) the sides of each triangle belong one to each of three groups into which the whole set of lines can be divided. The theorem itself follows, conversely, if this proposition be independently proved.

9. In No. 494 of the *Astronomische Nachrichten*, CLAUSEN has a problem closely connected with the present subject. It refers to the minimum number of separate strokes of a pen by which a given figure consisting of lines can be drawn. LISTING, in his *Vorstudien zur Topologie*, has shown how to find this minimum number by counting the points at which an odd number of lines meet. In our present proposition, if one polygon can be found containing all the points, *it* and *one* of the unused lines together form *one* penstroke, and the remaining group of $n-1$ unused lines forms the rest. If there be two polygons, they and one of the unused lines together form one penstroke. And so on.

10. To apply the result above to the problem of map-colouring, insert a new district surrounding each point of the map where more than three boundaries meet. Then divide the boundaries, which now meet in threes, into three groups as above. (The excepted case obviously cannot arise). Now let **O** separate the colours A and B, or C and D; **I**, A and C, or B and D; and **II**, A and D, or B and C; and the thing is done. For we may now suppose the inserted districts to become smaller, till they vanish.

XXIV.—*On the Structure and Arrangement of the Soft Parts in* Euplectella aspergillum. By Professor FRANZ EILHARD SCHULZE, Graz. Communicated by Sir WYVILLE THOMSON, V.P.R.S.E. (Plate XVII.)

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Although, from the careful descriptions which have been given by several competent naturalists, we may now consider ourselves tolerably well acquainted with the structure of the dainty siliceous skeletons of this and several allied Hexactinellid Sponges, this is by no means the case with their soft tissues; and the great cause of our imperfect knowledge of these interesting structures is that no observer has hitherto succeeded in procuring a really well-preserved Sponge of this group. It was with pleasure, therefore, that I accepted the offer of the Director of the Challenger Expedition to place some well-preserved examples belonging to different genera in my hands for investigation. Of all the specimens which have been sent to me, some fragments of *Euplectella aspergillum* in absolute alcohol are much the best preserved, and therefore the best suited for thorough examination. I commence with the description of the soft parts of this well-known and beautiful form, following the classification which has been adopted by Sir WYVILLE THOMSON in his descriptions of the species.

1. ON THE SOFT PARTS OF *Euplectella aspergillum* (R. OWEN).

I received in January 1880, from the Challenger Office in Edinburgh, an entire specimen of *Euplectella aspergillum* preserved with its soft parts in methylated spirit, and six bottles containing fragments of the same species preserved according to different methods, viz.:—

1. In picric acid.
2. In solution of acetate of potash, after previous treatment with osmic acid.
3. In chromic acid.
4. In glycerine, after previous treatment with nitrate of silver.
5. In absolute alcohol, after previous colouring with carmine.
6. In absolute alcohol simply.

I will commence with a short abstract of previous communications on the subject by other naturalists.

In 1868, after examination of dried fragments, Sir WYVILLE THOMSON characterised the soft parts of the Hexactinellidæ, which he supposed to be simple sarcode, as follows: "It is small in quantity, very soft, probably semi-fluid, extending in a thin layer over the siliceous needles and over the siliceous framework. It appears to contain no trace of the diffused granular horny matter with which the more consistent sarcode of the Halichondridæ is so often loaded."*

On the other hand, BOWERBANK in the following year (1869) maintained, with reference, however, to certain sponges which he erroneously considered genuine Hexactinellidæ, that the soft mass in the Hexactinellidæ was in no less quantity than in other sponges, and that in *Hyalonema* the spicules are held together by a horny substance.† At the same time OSCAR SCHMIDT, after examining spirit specimens of different Hexactinellidæ, agreed with Sir WYVILLE THOMSON as to the consistency and quantity of the sarcode,‡ while on the other hand GRAY,§ in 1872, found two spirit specimens, brought by A. B. MEYER from the Philippines, "entirely covered by a thick coat of sarcode, like the bark on a *Gorgonia*, but softer, so that the siliceous fibres are entirely hidden from view. No one would suspect that this sponge had such a beautiful lace-like structure, but would suppose that it was simply a netted or pierced tube, with irregular, circular, thicker hoops. The flesh or sarcode is of a dark-brown colour, but is most likely coloured by the action of the spirit." More complete information was given in 1875 by MARSHALL,‖ who had an opportunity of examining some pieces of a *Holtenia* and of *Euplectella aspergillum*, which were tolerably well preserved in spirit. He described the most of the soft parts as a clear, viscid substance, the sarcodine somewhat consistent only in the neighbourhood of the bundle of needles, and containing here and there some elliptical round nuclei, with nuclear corpuscules and numerous fine granules. The latter appeared sometimes isolated, sometimes united in rounded masses, and sometimes aggregated in the immediate neighbourhood of the nuclei. In *Euplectella* the sarcodine is of a greenish colour, but nowhere so transparent and hyaline as in many parts of *Holtenia;* in which, however, the sarcode is also rendered turbid by very fine rounded particles.

Since MARSHALL'S paper, I am aware of several short notices on the nature of the soft parts of Hexactinellidæ, and especially those of *Euplectella,* which Sir WYVILLE THOMSON has incidentally interwoven with his preliminary report of his great exploring journey, and of which the following are the most important: "In fresh specimens of *Euplectella aspergillum* the crystal framework is covered, and entirely masked by a layer of *grey-brown gelatinous* matter.¶

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* Ann. and Mag. Nat. Hist., New Series, vol. i. p. 120.

† Proc. Zool. Soc., 1869, p. 344.

‡ Prodromus of a Sponge-fauna of the Atlantic region, 1870, p. 13.

§ Ann. and Mag. Nat. Hist., New Series, vol. x. p. 139.

‖ Zeit. für Wiss. Zool., Band xxv. p. 142.

¶ The Atlantic, p. 136.

Of the specimens of *Euplectella* from the Challenger collection, preserved in so many different ways, those only which were simply preserved fresh in absolute alcohol proved suitable for the study of the soft parts. In the specimens which, with the adherent sarcode, had been preserved in methylated spirit, as well as in the fragments preserved in glycerine after previous treatment with nitrate of silver, the soft parts had certainly kept their form and arrangement, but they showed little of the detail of structure. In the specimens in picric acid, in the specimen preserved in chromic acid, and in that preserved in acetate of potash after previous treatment with osmic acid, the soft parts had almost entirely separated from the skeleton, and formed a sediment at the bottom of the vessel. In the pieces which had been dyed with carmine, and then preserved in absolute alcohol, the soft parts had become so friable as to break in pieces when touched.

The results of my investigations, which I now communicate, are therefore almost entirely obtained from the pieces preserved in absolute alcohol, and as these pieces were all taken from the side wall of the sponge, I was obliged, in order to study the remaining regions of the sponge, and especially the cribriform opercular plate, and the end portion which was buried in the mud, to use some of the pieces which were not so well preserved, and particularly the large one in methylated spirit.

On the portions which were free from mud and other impurities, the soft parts had a pale yellowish-grey colour, and were but scantily developed. They consisted of a substance of the consistency of crum of bread, extending between the meshes of the framework of siliceous threads and the adherent or free siliceous spicules, and the soft matter is traversed by so many passages and hollow spaces that it is nowhere compact, but forms rather a *delicate meshwork* of fibres or membranes. This soft substance is most abundant in the tube-shaped wall which forms the principal part of the sponge, in the flat thinner portion of the tube as well as in the ridges which project from its outer surface, and to which the collar-like border of the terminal cribriform plate also belongs.

We see in a well-preserved piece of the tube-wall that the circular apertures in the skeleton, which are arranged at pretty equal distances in oblique or rather in spiral rows crossing one another, and which mark the angles of rhomboidal fields of nearly equal size, correspond also to circular apertures about 2 mm. in diameter through the entire wall of the tube, by means of which the water surrounding the sponge communicates directly with that contained in its inner cavity.

The margin of these circular wall-openings (as I shall henceforth call them) consists of a rather thin ring of membrane, which lies considerably nearer the inner than the outer surface of the wall which is nearly 3 mm. thick; so that each opening corresponds with a dimple-like depression on the external surface of the sponge. Between each four apertures which bound each rhomboidal field, a more or less rounded knob projects, which is separated from the nearest similar projection by shallow groove-like depressions, which correspond with the oblique connecting grooves of the wall-apertures (Pl. XVII. fig. 1). In many places, however, the bosses arranged in oblique series are fused together into more or less prominent ridges, sharp along the top and with tolerably steep walls,—the so-called "combs,"—whose form and arrangement is so well seen in the macerated skeleton.

I must, however, draw attention to the fact that the whole external surface of the tube, which shows a rather complicated relief, possesses no openings visible to the naked eye except these wall-apertures, but is covered by a continuous connecting membrane. Every small irregular roundish darker mark which we notice in strong light corresponds to a subdermal hollow space which shines through this thin membrane (Pl. XVII. fig. 1). The inner surface of the tube-wall does not appear so uneven. Between transverse annular beams of spicules, which project only slightly towards the interior, there are flat groove-like depressions, which divide the still less prominent longitudinal beams of the siliceous network into square areæ of nearly equal size. The areæ thus separated by bounding ledges of different heights show, alternating tolerably regularly, either regular gaps perforating the tube, or less regular roundish excretory openings of cæcal spaces in the wall of the sponge (Pl. XVII. fig. 2). Here and there deviations from the regular alternation of the two kinds of areæ appear in the longitudinal and transverse rows, but these are only isolated, and occur usually where one of the longitudinally directed bands of siliceous fibres divides towards the broader upper end of the tubes, leading to the formation of a new longitudinal row of areæ, by which the symmetry of the structure is somewhat disturbed; whilst the areæ, furnished with wall-openings, only show round the iris-like margin of these central openings a simple circle of small roundish excretory pores, of short water-ducts; the areæ alternating with these show a somewhat important differentiation, as they sometimes contain only one or two, rarely three, large round openings of well-marked exhalent canals, sometimes a larger number of smaller openings of shorter wall-canals. We find that the areæ with the larger ducts always lie under a *comb*, whilst those furnished with numerous smaller openings correspond to the boss-like projections which are found where there is no comb. We find accordingly the areæ with the large openings arrayed in oblique rows, which correspond with the combs (Pl. XVII. fig. 2).

The soft parts are feebly developed on the cribriform plate, more or less arched, and with large irregular meshes, which closes the upper end of the tube. At most the layer of soft matter is developed comparatively thickly here and there externally, while the side and inner surfaces of the siliceous beams, which are here particularly strong and thick, are only covered by a thin membrane. At the lower extremity of the sponge the soft parts end with the netting of the tube-wall. The terminal tuft of long siliceous hairs, which serve to anchor the sponge in the ooze, show no appreciable soft parts.

As in other sponges, we can only obtain a clear idea of the structure of the soft parts, and of their relation to the skeleton in *Euplectella*, by the preparation and careful study of thin sections.

Tinging with different dye-matters is of essential service for defining the differentiation of tissues and their peculiar cell-elements.

To make preparations which answer both purposes I proceeded as follows:—

Pieces from the size of a pea to that of a bean were cut with fine scissors from the fragments which had been preserved in absolute alcohol, and freed from the excess of alcohol by being laid on blotting paper for a little. They were then tinged, some with picro-carmine, some with aloin-carmine, and others with hematoxylin, for which, as a rule, from six to twenty-four hours was necessary. After the pieces so dyed had been well washed in distilled water, they were laid in alcohol of 52°, then in alcohol of 60°, and by gradual concentration were finally brought to absolute alcohol. Out of this they were put next day in a mixture of absolute alcohol and xylol, and finally in oil of turpentine. Completely drained in this way, they were embedded in paraffin, and divided by Leyser's microtome in different directions into fine sections, which, after the paraffin has been removed by warm oil of turpentine, were preserved in Canada balsam.

A good general view of the arrangement of the soft parts is most easily got by a fine section of the tube-wall, taken transversely through a *comb* at a point where the inner surface of the wall shows a quadrate area with a large canal opening. I have figured such a section (Pl. XVII. fig. 3) in a combination figure, *i.e.*, in a drawing as like nature as possible, made up from several preparations, fifteen times the natural size. We observe, in the first place, that the whole external surface is covered by a delicate membrane, which extends between the outer points of the radiating rapier-like six-rayed spines and the floricome-hexradiate spicules of Bowerbank * which always lie close to the rapier hilt, in such a fashion that it always appears more or less depressed in the middle between each group of the four rapier hilts and floricomes which mark the four corners of a quadrate area. This membrane, which may be simply called the skin, when seen from above (Pl. XVII. fig. 5), is pierced like a sieve with numerous round or oval holes of different sizes. These dermal pores are only wanting

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* For shortness I will call the dainty six-rayed stars, composed of six eight-membered structures like the cup of a flower, "floricomes."

where the skin is stretched above between the sword hilts and the floricomes. The width of the dermal pores corresponds generally with the stricture of the dermal septa which surround them, and it appears, as in other sponges, to alter frequently in life.

The water first passes through the dermal pores into subdermal spaces, which are here represented by a wide-meshed lacunar network between the external skin and a fenestrated layer of tissue extending in the plane of the lateral cross-rays of the radiating rapier-like spines.

In his "Untersuchung über Hexactinelliden," MARSHALL described and figured (fig. 62) as *skin* a membrane which extends between the lateral cross-rays of the rapier-shaped spines in such a way that one quadrate area limited by these cross-rays contains a single round hole, which may be called a dermal pore. Though I am willing to believe that in young individuals the outer layer may, under certain circumstances, contain only such distant and isolated pores, certainly in fully developed animals the outer film does not extend between the cross-rays of the rapier hilt, but, as above described, further out between the ends of the rapier hilts and the floricomes appended to them. What really stretches between the cross-rays of the rapier hilts is not so much a true membrane as a very wide-meshed network of delicate threads, from which similar bands or cords of tissue proceed not only towards the exterior to be connected with the true outer membrane, but also mid-cords in the form of an open, very irregular meshwork. They traverse wide lacunar spaces, extending from the cross-rays of the rapiers between their long processes, which correspond with the sword-blade, and here and there, by extension to deep fissures and passages, at length acquire the significance of water canals. In fact the periphery of this very irregular system of lacunæ and canals becomes towards the interior a complete system of flagellate chambers (ampullaceous sacs, CARTER), which I now proceed to describe.

Each individual chamber has the form of a sac more or less deep, nearly circular in transverse section, with the blind end semicircularly arched, and the almost circular opening placed transversely to the long axis of the sac. The length is on an average about 100 μ., but may vary between 60 μ. to 150 μ. The breadth is usually about 60 μ., varying, however, between 40 to 80 μ. Besides accidental flaws, which are frequently caused by the hardening and further treatment of the preparation, there are often actual variations in form. I will only draw attention here to one of these, which occurs so repeatedly that it can hardly be regarded as a mere abnormality. There are sometimes chambers which are bisected at the bottom by a larger or smaller constriction, while the remaining portion and the aperture remain single. I leave it an open question whether or not in such cases we have to deal with an actual process of division.

The membranous wall, which is usually very delicate and thin, is furnished with smooth-edged roundish *pores* of different sizes, irregularly arranged, and varying very much in number. These form an open communication between the cavities of the chambers and the duct-like spaces surrounding them, which as cleft-like diverticula of the inhalent lacunar system, penetrate everywhere between the ciliated chambers, and extend even to the oral edges of the chambers, where they end in a somewhat tough and solid membrane, which bounds and connects laterally the chamber walls (Pl. XVII. fig. 4). Besides this membrane there extends beyond the oral edges of the neighbouring chambers, which here and there touch one another and partly adhere, numerous flat or linear cords of tissue proceeding from the chamber walls, traversing the surrounding spaces, and serving to keep the chambers expanded and in position.

The general arrangement of the chambers is best understood by the disposition of the exhalent canal system, as they almost all run into it. These exhalent passages begin with digitate cæca of 100 to 200 μ. in transverse sections, which open terminally or laterally into wide canals. These latter open either directly by a round aperture through the inner wall of the sponge-tube, or are again united into still larger canals, which open with a circular aperture about 3 mm. wide into the large cavity of the sponge.

It is to be observed that in the whole inner surface of this exhalent canal system there stretches a network consisting of flat or thread-shaped bands of tissue, in which, besides the long five- or six-rayed spicules, numerous free starlets appear, which Bowerbank called "trifurcate hexradiate stellate spicules," and which, although in lesser number, are also found in the cords of tissue which traverse the inhalent lacunar system. I may here incidentally remark that the number of pointed secondary rays proceeding from each of the six principal rays of these stars need not necessarily be three, but may be four, or even five, but the number is always the same at all the six points of one and the same star.

The inner surface of the large excretory canals coming out from the ridges is formed of an extended, almost membranous, network, which stretches between the terminal crosses of the long-stalked five-rayed spicules, which are numerous here, and surround the quadrate meshes.

The structure of each portion of the tube-wall, which projects externally between the ridges in the form of flattened bosses, corresponds essentially to this structure of the ridges. As a difference it may, however, be noted that the exhalent canals, which are here naturally much shorter, are not united into one or two larger principal excretory openings, but open directly into a large number of pores close to one another in a quadrate area in the inner side of the sponge-tube: this is the cause of the groups already mentioned of smaller roundish excretory openings under each external boss, and which may be easily distinguished even by the naked eye from the large pores in the area under the ridge.

The portions of the sponge-tube surrounding the wall-openings in the form of a flat circular margin differ essentially from the thicker parts, as they have no ciliated chambers, and are not traversed by a lacunar system. MARSHALL had already conjectured that the wall-openings may act like a sphincter by means of a membranous margin supported by a circle of siliceous spicules, and that in this way the openings may vary in size. These wall-spaces cannot, however, be compared with the oscula of other sponges, as the latter always serve as the exhalent openings for the water canal system. The cribriform operculum at the upper end of the sponge may be rather considered as representing an oscular region, whilst the round wall-openings in *Euplectella* probably only serve for the free lateral entrance or exit of the surrounding water.

The idea expressed by CLAUS * that the *Euplectella* as a whole may be compared to a tube-shaped *sycon*, in which the separate boss-shaped projecting thickenings of the wall, as well as their corresponding ridges, may be considered as homologous to the radial tubes; the circular wall-openings to the intercanals, and finally the upper cribriform opercular plate to the wider oscular opening of the *sycon*, is therefore inadmissible, as we can only possibly compare the single sac-shaped ciliated chambers of *Euplectella* to the single radial tube of a *sycon*, and not an entire system of such chambers with branched excretory passages such as we have in each projecting knob or ridge. MARSHALL had already observed this, and, with more special reference to the relations of the spaces in the tube-wall of *Euplectella*, had attempted a more justifiable comparison with a *Leuconpersona*.

The whole structure of the cribriform opercular plate indicates that it is an oscular region serving as the last passage of exit for the discharged water, since the inner and side surfaces of the small lattice-beams are quite flattened, as if worn away by the ejected water, while the outer surface only is furnished with a small quantity of soft substance containing ciliated chambers, and is covered by the same skin which we find on the ridges and bosses of the tube-wall.

After this explanation of the general arrangement of the soft parts of *Euplectella aspergillum*, I will now consider its histological structure more in detail.

Here, as in all sponges which I have closely examined hitherto, we can

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* Ueber *Euplectella aspergillum*, 1868.

distinguish three different layers of tissue corresponding to the layers of the germ.

The whole free external surface of *Euplectella,* as well as the inner wall and the hollow spaces and canals which conduct the water from the external pores to the ciliated chambers, are covered by an epithelium composed of a single layer of thin flat cells, which, from the developmental observations which I have recently made upon *Plakina,** I regard as proceeding in this, as in other sponges, from the ectoderm of the larva, and I shall therefore simply call it *ectoderm.*

A like simple layer of epithelium which lines the ciliated chambers themselves, as well as the whole exhalent canal system extending from the mouths of the ciliated chambers to the oscular openings, I call *endoderm* for the same reason. Finally, I consider as *mesoderm* the whole mass of connective tissue between these two layers, which represents the stroma of the skeleton and of the genital products.

The Ectoderm.—In most sponges we can only succeed under specially favourable circumstances in detecting in the living animals the limits of the ectodermal cells, though it is easy to observe them by the use of nitrate of silver. I never succeeded in showing the limits of the cells in spirit specimens, and consequently I could not expect to see them in this case, since they can be brought into view by no known process. Of course, it by no means follows that the layer of ectoderm cells is wanting. On the other hand, I find their presence indicated, if not by the outlines of the cells, by the characteristic cell-nuclei, which, like the neuclei of the ectoderm cells of other sponges, are distinguished by their circular form, by their fine refractive nuclear corpuscles, and here especially by their minuteness compared with the oval, paler, and larger cells of the underlying connective tissue (Pl. XVII. fig. 5).

Besides, the situation of these small round nuclei, in the uppermost layer, directly washed by the water, their partial projection when seen in profile, and their tolerably regular distribution, are in support of the view of the existence of such a layer of ectoderm cells.

The Endoderm.—That part of the epithelial layer termed *endoderm,* which lines the exhalent vessels from the openings of the ciliated chambers to the oscular openings of the cribriform operculum, here, as in all other sponges, closely resembles the flat ectodermal epithelium, whilst that portion of the endoderm which lines the ciliated chambers is of an entirely different character.

Although even the excellent state of preservation of the materials at my

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* Zeit. für Wiss. Zool., Band xxxiv.

disposal was not sufficient to allow me to gain a clear idea of the nature of the epithelium of the ciliated chambers, I was able to observe the following facts. I could perceive all the cells in the form of aggregated roundish lumps, in the centre of which a small spherical nucleus, furnished with a smaller strongly refractive nuclear corpuscle (like that which appears in the collar-cells of other sponges), was sharply defined by means of a tinging medium (Pl. XVII. figs. 6 and 7). If, therefore, nothing was to be observed in my preparations of the cylindrical form of the cells, of the peculiar collar-like process, of the collar, or of the flagellum which appears in the collar-cells of other sponges, it by no means follows that they are wanting in the living animal. The fact that in this case the cells of the ciliated chambers do not touch each other immediately laterally, but lie apart at nearly equal distances, did not surprise me, as I had occasionally found the same in other sponges—for example, in *Spongelia*—in pieces which had not been quite sufficiently hardened for examination. On the other hand, the peculiar arrangement and lateral connection of the cells with each other seemed to me highly remarkable.

Even under a comparatively low magnifying power we can see a reticulate arrangement in the ciliated chambers, which has never yet been described in any other sponge. The cells, which are arranged in spiral or oblique rows, and lie somewhat apart, are connected in such a way by tolerably strong refractive straight cords, that rhomboidal quadrate meshes are formed which are usually of nearly equal size, and only here and there become varied in form and arrangement by the pores of the chambers. While usually four such lateral connecting cords, forming a straight or oblique cross, proceed to the adjacent cells, there are not rarely five or six such processes. I could not find any complete explanation of the nature of these connecting cords and their relation to the cells; but I believe we must consider them as connecting bridges between the viscid cell bodies.

The Mesoderm.—In contrast to most other siliceous sponges, the scanty gelatinous connective tissue of the mesoderm has a semi-fluid colourless fundament basis, hyaline in itself, but rendered turbid by numerous irregularly scattered fine darker particles. The sort of difference which we have in many horny and siliceous sponges, between the equally dark granuled boundary of the ciliated chambers and the rest of the hyaline masses of connective tissue, is not to be observed here. Besides the small round nuclei of the outer epithelium, more faintly defined and usually oval-shaped nuclei, at whose narrow end we often find a still smaller nuclear mass, may be observed in the cribriform layer, as well as in the flat plates and cords of the remaining soft parts. I have, therefore, less hesitation in referring these pale oblong nuclei to the cells of the connective substance, as they are tolerably equally distributed in the fundamental basis, and, in conjunction with their scanty protoplasmic areæ, resemble the cells of connective tissue in other sponges. Besides these ordinary corpuscles of the connective tissue, I met with roundish balls of strongly refractive spherules, plentiful in some places, scanty in others (Pl. XVII. fig. 8), like those described by MARSHALL in the soft parts of different Hexactinellidæ, and especially of *Euplectella aspergillum.** I consider these granular balls, which certainly belong to distinct cells, as accumulations of reserve nutrition, somewhat comparable in a physiological sense to fat or starch.

The Genital Products.—I found numerous sperm balls of about 50 μ. in diameter in the meshes of the connective tissue, between the meshes of the ciliated chambers (Pl. XVII., fig. 6). The fine thread-shaped appendages were certainly no longer recognisable on the small sharply-defined, tolerably refractive roundish spermatozoa, which were aggregated in clusters in an enclosed space; but I have no doubt as to their signification, as they coloured deeply with carmine or logwood, like the moving sperm masses of the sponges.

Like most sponges, *Euplectella aspergillum* is inhabited by different commensals. While some of these, such as the much talked of crabs of the genera *Palœmon* and *Æga,* live enclosed like prisoners in the large cavity of the sponge, and others among the long spicules of the beard, another group are found in the soft parts of the tube-wall. From these last I here select for description a microscopic hydroid polyp, which appeared so abundantly in the *Euplectella* from Zebu, preserved in absolute alcohol, that one or more hydranths are found in almost every microscopic section of the tube-wall.

It belongs to the group of gymnoblastic hydroids of ALLMAN. The simple tube-like cœnosarc of the hydrophyton, which traverses the soft parts of the sponge in the form of a long-meshed net, is attached by isolated pointed ectoderm processes to the inner surface of a delicate annulated perisarc tube. From this cœnosarc tube, which is only about 20 μ. wide, more definitely at right angles than the branches forming the network of the tube, there spring simple club-shaped hydranths, which project without hydrothecæ freely into the inhalent lacunæ, and therefore towards the exterior, from the zones of ciliated chambers.

Each hydranth has, close beneath the short hemispherical hypostoma, with its terminal oral opening, only two opposite annulated comparatively long solid tentacles with a terminal knob richly loaded with sting-capsules, and rather

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* Zeitschrift für Wissen. Zool., Band xxv. p. 159, and Pl. xiii. fig. 6 Pl. xv. fig. 60.

below this a semicircular internal transverse enlargement, with a like thickening also with numerous sting-capsules. The remaining portions of the arm are quite flat.

The thread-cells, which, besides appearing in the ectodermal thickening of the arms, are also found, though isolated and not yet in a vertical position, in the endodermal layer of the cœnosarc, resemble in shape the broad sting-capsules of *Hydra*, although they do not attain to so great a size.

The endoderm of the cœnosarc contains flat cells, but in the hydranth bodies it consists of tall clear ciliated cells. As direct processes of the endoderm layer, a single row of columns, formed of clear cells, stretch to the terminal knobs of the arms.

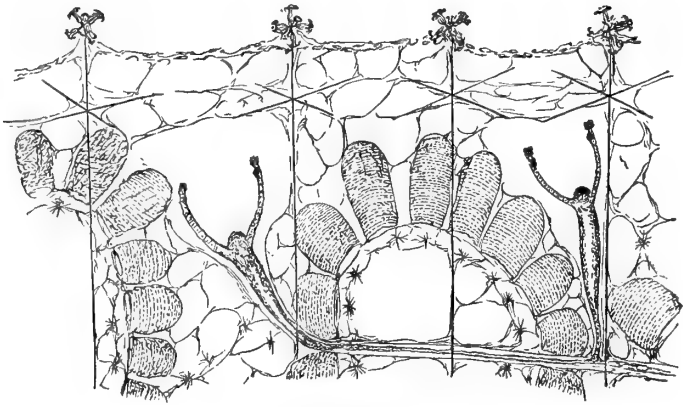

Fig. 1. *Amphibrachium euplectellæ* (Schulze).
The Hydroid *in situ*, infesting the soft tissues of *Euplectella*. × 60.

A simple layer of very delicate, hyaline, supporting lamellæ, are found in the outer surface of the arms, as well as in the body of the hydranth.

Reproductive buds could unfortunately not be observed.

On account of the number and situation of the arms, I call this commensal of *Euplectella aspergillum*, given sixty times the natural size in the above woodcut, *Amphibrachium euplectellæ*.

EXPLANATION OF PLATE XVII.

Fig. 1. Part of the outer surface of the tube-wall of *Euplectella aspergillum*, from the Zebu specimen preserved in absolute alcohol. Natural size.

Fig. 2. Part of the inner surface of the tube-wall of the same sponge. Natural size.

Fig. 3. Transverse section of a ridge, with part of the tube-wall of the same sponge. The section corresponds to one of the larger efferent openings of the exhalent canal system. × 16. A combination figure.

Fig. 4. Outer portion of a thin section taken perpendicularly to the outer surface through the side wall of a ridge. × 150.

Fig. 5. External view of a small piece of the outer membrane from the side wall of a ridge. × 400.

Fig. 6. Transverse section of a layer of ciliated chambers with a sperm-sphere. × 400.

Fig. 7. Part of the wall of a ciliated chamber. × 600.

Fig. 8. A small portion of the network of the exhalent lacunar system of a ridge. × 600.

XXV.—*On Minding's Theorem*. By Professor TAIT.

(Revised June 23, 1880.)

The following paper contains a short digest of investigations communicated to the Society on several occasions during the past, and the present, session. The work had been for some months laid aside, but my attention was recalled to it by Professor CHRYSTAL'S valuable paper, in which he treats MINDING'S Theorem as an example of PLÜCKER'S methods, and also by the help of RODRIGUES' co-ordinates. I am induced to publish a few of my results in full, as I think that a comparison of the analysis employed by CHRYSTAL, with the very different analysis employed by myself, may be useful as well as interesting, especially from the point of view of the simplicity of the quaternion method. Even when the quaternion processes are written out at full length, they are in general shorter than the most condensed forms of ordinary analysis; and there can be no doubt that they are much more easily interpretable into the corresponding geometrical ideas.

A hastily-written proof of the main theorem, somewhat on the same lines as the first of those now given, was printed in the "Proceedings of the London Mathematical Society," No. 147. But the present version is much simpler; and it is requisite for the intelligibility of the rest of the paper which, I repeat, is given mainly for the sake of the quaternion processes involved.

I commence with a few preliminary transformations. This would be altogether needless if quaternion methods were at all as familiar to the majority of mathematical readers as are the more usual ones.

1. In what follows we have a good deal of use to make of certain properties of linear and vector functions, so that some of the less obvious of them are here briefly stated.

Let α_1, α_2, &c., β_1, β_2, &c., be any two sets of vectors, and let us consider the vector

$$\kappa = \Sigma \mathrm{V}\beta\alpha. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

If we operate by $\mathrm{V}.\sigma$, where σ is any vector whatever, we have

$$\begin{aligned} \mathrm{V}\sigma\kappa &= \mathrm{V}.\sigma\Sigma\mathrm{V}\beta\alpha \\ &= \Sigma(\alpha\mathrm{S}\beta\sigma - \beta\mathrm{S}\alpha\sigma) \\ &= (\phi - \phi')\sigma \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2) \\ &= 2\mathrm{V}\epsilon\sigma \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3) \end{aligned}$$

if $\mathrm{V}.\epsilon$ be the impure part of the strain

$$\phi = \Sigma\alpha \mathrm{S}\beta(\;) \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

Hence if ϕ be put (as can always be done) in the normal form

$$\zeta \mathrm{S}i(\;) + \eta \mathrm{S}j(\;) + \theta \mathrm{S}k(\;)\,,$$

where i, j, k form a rectangular unit system; we have

$$\kappa = \Sigma \mathrm{V}\beta\alpha = \mathrm{V}(i\zeta + j\eta + k\theta) \quad . \quad . \quad . \qquad (5)$$

In the particular case which we shall chiefly require, it will be found that there is a certain vector $\bar{\beta}$ such that

$$\phi\bar{\beta} = 0.$$

Hence we may write ϕ in the form

$$\gamma'\mathrm{S}\gamma(\;) + \delta'\mathrm{S}\delta(\;)$$

where γ, δ are any two unit vectors perpendicular to each other and to $\bar{\beta}$. If, now, we change

$$\gamma \text{ to } \gamma\cos\vartheta + \delta\sin\vartheta\,,$$

and

$$\delta \text{ to } -\gamma\sin\vartheta + \delta\cos\vartheta\,,$$

(which are still unit vectors, perpendicular to one another, and to β)

$$\gamma' \text{ becomes } \gamma'\cos\vartheta - \delta'\sin\vartheta\,,$$

and

$$\delta' \quad \text{,,} \quad \gamma'\sin\vartheta + \delta'\cos\vartheta\,.$$

These are at right angles to one another if

$$\tan 2\vartheta = \frac{2\mathrm{S}\gamma'\delta'}{\delta'^2 - \gamma'^2}\,.$$

This always gives real values of ϑ, corresponding to two definite directions at right angles to one another. Hence we may always take

$$\phi = \gamma'\mathrm{S}\gamma(\;) + \delta'\mathrm{S}\delta(\;) \quad . \quad . \quad . \quad . \qquad (4')$$

where γ and δ are as before, and γ' and δ' are vectors at right angles to one another.

Another point to be borne in mind is that rotation of a rigid system may be expressed by a special linear and vector function, χ, which possesses the following characteristic properties;

$$S\chi\alpha\chi\beta=S\alpha\beta\,,$$

(of which a particular case is

$$T\chi\alpha=T\alpha,)$$

and

$$V\chi\alpha\chi\beta=\chi V\alpha\beta\,.$$

Also the conjugate of χ is its reciprocal, or

$$\chi'=\chi^{-1}\,.$$

These premised, we may attack the question.

2. When any number of forces act on a rigid system; β_1 at the point α_1, β_2 at α_2, &c., their resultant consists of the single force

$$\bar{\beta}=\Sigma\beta$$

acting at the origin, and the couple

$$\kappa=\Sigma V\beta\alpha\,. \qquad (1)$$

If these can be reduced to a single force, the equation of the line in which the force acts is evidently

$$V\bar{\beta}\rho=\Sigma V\beta\alpha\,. \qquad (5)$$

Now suppose the system of forces to turn about, preserving their magnitudes, their points of application, and their mutual inclinations, then MINDING'S Theorem, proved (in CRELLE'S "Journal," vols. xiv., xv.) by an excessively elaborate process, assigns certain fixed curves in space, each of which is intersected by the line (5) in every one of the infinite number of its positions.

3. To prove this, and to find the curves in question, we may proceed as follows:—

Operating on (5) by $V.\bar{\beta}$, it becomes

$$\rho\bar{\beta}^2-\bar{\beta}S\bar{\beta}\rho=\phi\bar{\beta}-\phi'\bar{\beta}$$

with the notation of (2). Now, however the forces may turn,

$$\phi\bar{\beta} = \Sigma\alpha S\beta\bar{\beta}$$

is an absolute constant; for each scalar factor as $S\beta_1\bar{\beta}$ is unaltered by rotation. Let us therefore change the origin, *i.e.*, the value of each α, so as to make

$$\Sigma\alpha S\beta\bar{\beta} = 0\,,$$

i.e.,

$$\phi\bar{\beta} = 0 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Thus we see that ϕ may be expressed in the form given in (4′) above.

4. Equation (5) is now

$$b\mathrm{V}\beta\rho = \mathrm{V}\gamma\gamma' + \mathrm{V}\delta\delta', \quad . \quad . \quad . \quad . \quad (5')$$

where b is the tensor, and β the versor, of $\bar{\beta}$.

The condition that the force shall lie in the plane of the couple is, of course, included in this, and is found by operating by $S.\beta$. Thus

$$S(\delta\gamma' - \gamma\delta') = 0 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

We have here all the data of the problem, and solutions can only differ from one another in the mode of attacking (5′) and (7). The most purely quaternionic mode, so far as HAMILTON developed his calculus, seems to be the following :—

Writing (7) in the form

$$S\gamma(\delta' + \mathrm{V}\beta\gamma') = 0\,,$$

we have at once

whence

$$\left.\begin{aligned} t\gamma &= \mathrm{V}\beta\delta' + \beta\mathrm{V}\beta\gamma', \\ t\delta &= -\mathrm{V}\beta\gamma' + \beta\mathrm{V}\beta\delta', \end{aligned}\right\} \quad . \quad . \quad . \quad (7')$$

where t is an undetermined scalar.

By means of these we may put (5′) in the form

$$\begin{aligned} bt\mathrm{V}\beta\rho &= \mathrm{V}.\beta(\mathrm{V}\gamma'\delta' + \gamma' S\gamma'\beta + \delta' S\delta'\beta) \\ &= \mathrm{V}.\beta(\mathrm{V}\gamma'\delta' - \varpi\beta) \end{aligned}$$

where

$$\varpi = -\gamma' S\gamma'(\ ) - \delta' S\delta'(\ ).$$

Let the tensors of γ' and δ' be e_1, e_2 respectively, and let β' be a unit vector perpendicular to them, then we may write

$$bt\rho = x\beta + e_1e_2\beta' - \varpi\beta, \quad . \quad . \quad . \quad . \quad (8)$$

Operating by $(\varpi - x)^{-1}$, and noting that

$$\varpi\beta' = 0\,,$$

we have

$$bt(\varpi - x)^{-1}\rho = -\beta - \frac{e_1e_2}{x}\beta'\,, \quad . \quad . \quad . \quad . \quad (8')$$

Taking the scalar of the product of (8) and (8′) we have

$$b^2t^2\mathrm{S}\rho(\varpi - x)^{-1}\rho = -\frac{1}{x}(x\beta + e_1e_2\beta')^2 - \mathrm{S}\beta\varpi\beta\,.$$

But by (7′) we have

$$t^2 = \mathrm{S}\beta\varpi\beta + e_1^2 + e_2^2 - 2e_1e_2\mathrm{S}\beta\beta' \quad . \quad . \quad . \quad (9)$$

so that, finally,

$$b^2\mathrm{S}\rho(\varpi - x)^{-1}\rho = -1 + \frac{(e_1^2 - x)(e_2^2 - x)}{xt^2} \quad . \quad . \quad . \quad (10)$$

5. Equation (10), in which t^2 is given by (9) in terms of β, is true for every point of every single resultant. But we get an immense simplification by assuming for x either of the particular values e_1^2 or e_2^2. For then the right hand side of (10) is reduced to negative unity, and the equation represents one or other of the focal conics of the system of confocal surfaces

$$\mathrm{S}\rho(\varpi - h)^{-1}\rho = -\frac{1}{b^2}\,,$$

a point of each of which must therefore lie on the line (8). This is MINDING'S Theorem.

6. A singular form, in which it can be expressed, appears at once from equation (5′). For that equation is obviously the condition that the linear and vector function

$$-b\rho\mathrm{S}\beta(\;) + \gamma'\mathrm{S}\gamma(\;) + \delta'\mathrm{S}\delta(\;)$$

shall denote a pure strain.

Hence the following problem:—*Given a set of rectangular unit vectors, which may take any initial position: let two of them, after a homogeneous strain,* *become given vectors at right angles to one another, find what the third must become that the strain may be pure.* The locus of the extremity of the third is, for every initial position, one of the single resultants of MINDING's system; and therefore passes through each of the fixed conics.

Thus we see another very remarkable analogy between strains and couples, which is in fact suggested at once by the general expression for the impure part of a linear and vector function.

7. The scalar t, which was introduced in equations (7′), is shown by (9) to be a function of β alone. In this connection it is interesting to study the surface of the fourth order

$$S\tau\varpi\tau-(e_1^2+e_2^2)\tau^2-2e_1e_2T\tau S\beta'\tau=1\,,$$

where

$$\tau=\frac{1}{t}\beta\,.$$

But this may be left as an exercise.

Another form of t (by 7′) is $S\gamma\gamma'+S\delta\delta'$.

Meanwhile (9) shows that for any assumed value of β there are but two corresponding MINDING lines.

If, on the other hand, ρ be given there are in general four values of β. For variety we may take a different mode of attacking equations (7) and (5′), which contain the whole matter. In what follows b will be merged in ρ.

8. Operating by $V.\beta$ we transform (5′) into

$$\rho+\beta S\beta\rho=-(\gamma S\gamma'\beta+\delta S\delta'\beta) \quad . \quad . \quad . \quad (5'')$$

Squaring both sides we have

$$\rho^2+S^2\beta\rho=S\beta\varpi\beta \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Since β is a unit vector, this may be taken as the equation of a cyclic cone; and every central axis through the point ρ lies upon it. For we have not yet taken account of (7), which is the condition that there shall be no couple.

To introduce (7), operate on (5″) by $S.\gamma'$ and by $S.\delta'$. We thus have, by a double employment of (7),

$$\left.\begin{aligned}S\gamma'\rho+S\gamma'\beta S\beta\rho&=S\gamma\varpi\beta\\ S\delta'\rho+S\delta'\beta S\beta\rho&=S\delta\varpi\beta\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Next, multiplying (11) by $S\beta\varpi\beta$, and adding to it the squares of (12), we have

$$\rho^2S\beta\varpi\beta-2S\beta\rho S\beta\varpi\rho-S\rho\varpi\rho=-S\beta\varpi^2\beta\,. \quad . \quad . \quad (13)$$

This is a second cyclic cone, intersecting (11) in the four directions β. Of course it is obvious that (11) and (13) are unaltered by the substitution of $\rho+y\beta$ for ρ.

If we look on β as given, while ρ is to be found, (11) is the equation of a right cylinder, and (13) that of a central surface of the second order.

9. A curious transformation of these equations may be made by assuming ρ_1 to be any other point on one of the MINDING lines represented by (11) and (13). Introducing the factor $-\beta^2(=1)$ in the terms where β does not appear, and then putting throughout

$$\beta \parallel \rho_1-\rho\,, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (14)$$

(11) becomes

$$-\rho^2\rho_1^2+\mathrm{S}^2\rho\rho_1=\mathrm{S}(\rho_1-\rho)\varpi(\rho_1-\rho) \quad . \quad . \quad . \qquad (11')$$

As this is symmetrical in ρ, ρ_1, we should obtain only the same result by putting ρ_1 for ρ in (11), and substituting again for β as before.

From (13) we obtain the corresponding symmetrical result

$$(\rho^2-\mathrm{S}\rho\rho_1)\mathrm{S}\rho_1\varpi\rho_1+(\rho_1^2-\mathrm{S}\rho\rho_1)\mathrm{S}\rho\varpi\rho=-\mathrm{S}\rho\rho_1\mathrm{S}(\rho_1-\rho)\varpi(\rho_1-\rho)-\mathrm{S}(\rho_1-\rho)\varpi^2(\rho_1-\rho) \quad . \quad (13')$$

These equations become very much simplified if we assume ρ and ρ_1 to lie respectively in any two conjugate planes; specially in the planes of the focal conics, so that $\mathrm{S}\delta'\rho=0$, and $\mathrm{S}\gamma'\rho_1=0$.

For if the planes be conjugate we have

$$\mathrm{S}\rho\varpi\rho_1=0\,,$$
$$\mathrm{S}\rho\varpi^2\rho_1=0\,,$$

and if, besides, they be those of the focal conics,

$$\mathrm{S}\rho\rho_1=-\mathrm{S}\beta'\rho\mathrm{S}\beta'\rho_1\,,$$
$$\mathrm{S}\rho\varpi^2\rho=e_1^2\mathrm{S}\rho\varpi\rho, \text{ \&c.},$$

and the equations are

$$-\rho^2\rho_1^2+\mathrm{S}^2\rho\rho_1=\mathrm{S}\rho_1\varpi\rho_1+\mathrm{S}\rho\varpi\rho\,, \quad . \quad . \quad . \quad . \qquad (11'')$$

and

$$\rho^2\mathrm{S}\rho_1\varpi\rho_1+\rho_1^2\mathrm{S}\rho\varpi\rho=-\mathrm{S}\rho_1\varpi^2\rho_1-\mathrm{S}\rho\varpi^2\rho\,. \quad . \quad . \qquad (13'')$$

From these we have at once the equations of the two MINDING curves in a variety of different ways. Thus, for instance, let

$$\rho_1=p\delta'$$

and eliminate p between the equations. We get the focal conic in the plane of

β', γ'. In this way we see that Minding lines pass through each point of each of the two curves; and by a similar process that every line joining two points, one on the one curve the other on the other, is a Minding line.

Another process is more instructive. Note that, by the equations of condition above, we have

$$S^2\rho\rho_1=\left(\frac{S\rho_1\varpi\rho_1}{e_2^2}-\rho_1^2\right)\left(\frac{S\rho\varpi\rho}{e_1^2}-\rho^2\right).$$

Then our equations become

$$\frac{S\rho\varpi\rho S\rho_1\varpi\rho_1}{e_1^2e_2^2}-\frac{\rho_1^2+e_1^2}{e_1^2}S\rho\varpi\rho-\frac{\rho^2+e_2^2}{e_2^2}S\rho_1\varpi\rho_1=0\,,$$

and

$$(\rho^2+e_2^2)S\rho_1\varpi\rho_1+(\rho_1^2+e_1^2)S\rho\varpi\rho=0\,.$$

If we eliminate ρ^2 or ρ_1^2 from these equations, the resultant obviously becomes divisible by $S\rho\varpi\rho$ or $S\rho_1\varpi\rho_1$, and we at once obtain the equation of one of the focal conics.

10. In passing it may be well to notice that equation (13) may be written in the simpler form

$$S.\rho\beta\rho\varpi\beta+S\rho\varpi\rho=S\beta\varpi^2\beta\,.$$

Also it is easy to see that if we put

$$\theta=\rho S\beta\rho-(\varpi+\rho^2)\beta$$

we have (11) in the form

$$S\beta\theta=0\,,$$

and by the help of this (13) becomes

$$\theta^2=S\rho\varpi\rho\,.$$

This gives another elegant mode of attacking the problem.

11. Another valuable transformation of (5″) is obtained by considering the linear and vector function, χ suppose, by which β, γ, δ are derived from the system β', $U\gamma'$, $U\delta'$. For then we have obviously

$$\rho=x\chi\beta'+\chi\varpi^{\frac{1}{2}}\chi\beta'\,. \qquad . \quad . \quad . \quad . \quad . \qquad (5''')$$

This represents any central axis, and the corresponding form of the Minding condition is

$$S.\gamma'\chi\varpi^{-\frac{1}{2}}\delta'=S.\delta'\chi\varpi^{-\frac{1}{2}}\gamma' \qquad . \quad . \quad . \quad . \qquad (7'').$$

Most of the preceding formulæ may be looked upon as results of the elimination of the function χ from these equations. This forms probably the most important feature of such investigations, so far at least as the quaternion calculus is concerned.

I employed the equation ($5'''$) as the basis of an investigation, one or two of whose results were communicated last session to the Society.* I will now give the main features of that investigation.

12. It is evident from ($5'''$) that the vector-perpendicular from the origin on the central axis parallel to $\chi\beta'$ is expressed by

$$\tau = \chi\varpi^{\frac{1}{2}}\chi\beta' .$$

But there is an infinite number of values of χ for which $\mathrm{U}\tau$ is a given versor. Hence the problem ;—to find the maximum and minimum value of $\mathrm{T}\tau$, when $\mathrm{U}\tau$ is given—*i.e.*, to *find the surface bounding the region which is filled with the feet of perpendiculars on central axes.*

We have

$$\mathrm{T}\tau^2 = -\mathrm{S}.\chi\beta'\varpi\chi\beta' ,$$

$$0 = \mathrm{T}\tau\mathrm{S}.\chi\beta'\mathrm{U}\tau .$$

Hence

$$0 = \mathrm{S}.\dot{\chi}\beta'\varpi\chi\beta' ,$$

$$0 = \mathrm{S}.\dot{\chi}\beta'\mathrm{U}\tau .$$

But as $\mathrm{T}\beta'$ is constant

$$0 = \mathrm{S}.\dot{\chi}\beta'\chi\beta' .$$

These three equations give at sight

$$(\varpi + u)\chi\beta' = u'\mathrm{U}\tau ,$$

where u, u' are unknown scalars. Operate by $\mathrm{S}.\chi\beta'$ and we have

$$-\mathrm{T}^2\tau - u = 0 ,$$

so that

$$\mathrm{S}\tau(\varpi + \tau^2)^{-1}\tau = 0 .$$

This differs from the equation of FRESNEL's wave-surface only in having $\varpi + \tau^2$ instead of $\varpi + \tau^{-2}$ $\left(i.e., \mathrm{T}\tau \text{ for } \frac{1}{\mathrm{T}\tau}\right)$, and denotes therefore the reciprocal

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* Proc. Roy. Soc. Edin., 1879, p. 200.

of that surface. In the statical problem, however, we have

$$\varpi\beta' = 0\,,$$

and thus the corresponding wave-surface has zero for one of its parameters.

[If this restriction be not imposed, the locus of the point

$$\tau = \chi\phi\chi\beta'\,,$$

where ϕ is now any given linear and vector function whatever, will be found, by a process precisely similar to that just given, to be

$$S.(\tau - \phi'\beta')(\phi'\phi + \tau^2)^{-1}(\tau - \phi'\beta') = 0\,,$$

where ϕ' is the conjugate of ϕ. This, however, has nothing to do with MINDING'S Theorem.]

13. As the reader may not feel secure of results derived by the differentiation of a vector function operator, it may be well to obtain the result of last section by a more usual process.

We obviously have by (5″)

$$\tau = \gamma S\gamma'\beta + \delta S$$

or (as in (11

$$\tau^2 = S\beta\varpi$$

But also

$$S\beta U\tau = 0\,.$$

$$\beta^2 = -1\,.$$

To make $T\tau$ a maximum with these conditions, we have

$$\left.\begin{aligned} S\dot\beta\varpi\beta &= 0 \\ S\dot\beta U\tau &= 0 \\ S\dot\beta\beta &= 0 \end{aligned}\right\}$$

and, by elimination of β and $\dot\beta$ among these equations, we have as before

$$S\tau(\varpi + \tau^2)^{-1}\tau = 0\,.$$

The first of the undifferentiated equations is that of an elliptic cylinder of variable magnitude but constant form and position, the second a diametral plane, and the third the unit sphere. Obviously there is one maximum and one minimum value of $T\tau$. These occur when the variable ellipse given by the first and second equation *touches* the fixed circle given by the second and third.

It may do so internally or externally, and consequently the resulting equation gives two values of $T\tau$ for each value of $U\tau$.

14. This is, in fact, in quaternions identical with the second process employed by Professor CHRYSTAL. For, by writing τ for $\rho+\beta S\beta\rho$ in (11) it becomes

$$\tau^2 = S\beta\varpi\beta ,$$

and in the same way (13) becomes

$$\tau^4 - S\tau\varpi\tau = -S\beta\varpi^2\beta .$$

These, translated into Cartesian scalars, are CHRYSTAL'S equations (8) and (9) (*Second Method, anté,* p. 523). They may be obtained directly by a process similar to that in section 8 above. CHRYSTAL'S first method is, of course, included in the solutions afforded by the use of χ.

I may remark, in conclusion, that the process of section 4, leading to an equation like (10) above, seems to be the most natural method of applying quaternions to questions connected with congruencies.

APPENDIX.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

1879-80.

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LIST OF MEMBERS,

INCLUDING

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ACCORDING TO DATE OF ELECTION,

AND

LIST OF FELLOWS DECEASED, RESIGNED, AND CANCELLED.

THE COUNCIL

OF

THE ROYAL SOCIETY OF EDINBURGH.

DECEMBER 1880.

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Lord Justice-Clerk, LL.D., President.

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OF

THE ORDINARY FELLOWS OF THE SOCIETY,

CORRECTED TO NOVEMBER 1880.

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1877		Hartley, Walter Noel, Professor of Chemistry, Royal College of Science for Ireland, Dublin	
1870		* Harvey, Thomas, M.A., LL.D., Rector of the Edinburgh Academy, 32 George Square	160
1859		* Hay, G. W., of Whitrigg, Devon Lodge, Starcross, Devon	
1855		Hay, James, 3 Links Place, Leith	
1880	P.	* Haycraft, J. Berry, M.B., B.Sc., Physiological Laboratory, University of Edinburgh	
1875		Hawkshaw, Sir John, Memb. Inst. Civil Engineers, F.R.S., F.G.S., 33 Great George Street Westminster	
1870		Heathfield, W. E., 20 King Street, St James, London	165
1862		* Hector, James, M.D., F.R.S., Director of the Geological Survey, Wellington, N.Z.	
1876	K. P.	* Heddle, M. Forster, M.D., Professor of Chemistry in the University of St Andrews	
1869		* Henry, Isaac Anderson-, of Woodend, Hay Lodge, Trinity	
1871		Higgins, Charles Hayes, LL.D., Alfred House, Birkenhead	
1859		Hills, John, Bombay Engineers	170
1879		Hislop, John, Secretary to the Department of Education, Wellington, New Zealand	
1828	P.	Home, David Milne, of Milne Graden, LL.D., F.G.S., President of the Geological Society of Edinburgh (VICE-PRESIDENT), 10 York Place	
1879		* Hood, Thomas H. Cockburn, F.G.S., Junior Carlton Club, Pall Mall, London	
1869		* Howe, Alexander, W.S., 17 Moray Place	
1872		* Hunter, Captain Charles, Pläs Cöch, Anglesea, and 17 St George's Square, London, S.W.	175
1864		* Hutchison, Robert (Carlowrie Castle), and 29 Chester Street	
1855		Inglis, Right Hon. John, D.C.L., LL.D., Lord Justice-General of Scotland, and Chancellor of the University of Edinburgh, 30 Abercromby Place	
1874		* Irvine, Alex. Forbes, of Drum, Advocate, Sheriff of Argyll, 25 Castle Terrace	
1875		Jack, William, M.A., Professor of Mathematics in the University of Glasgow	
1863		Jameson, William, Surgeon-Major, India	180
1860		* Jamieson, George A., 58 Melville Street	
1880		Japp, A. H., LL.D., 13 Albion Square, Dalston, London	

Date of Election.			
1869	K. P.	* Jenkin, H. C. Fleeming, F.R.S., Memb. Inst. Civ. Engineers, Professor of Engineering in the University of Edinburgh (VICE-PRESIDENT), 3 Great Stuart Street	
1865		* Jenner, Charles, Easter Duddingston Lodge	
1869		Johnston, John Wilson, M.D., Bengal	185
1867		* Johnston, T. B., F.R.G.S., 9 Claremont Crescent	
1874		Jones, Francis, Lecturer on Chemistry, Monton Place, Manchester	
1877		* Jolly, William, H.M. Inspector of Schools, Inverness	
1866		* Keiller, Alexander, M.D., F.R.C.P.E., 21 Queen Street	
1877		* King, James, of Campsie, Dean of Faculty of Glasgow University, 12 Claremont Terrace, Glasgow	190
1878		* King, William, M.A., Stewart Villa, Dean	
1880		* King, W. F., Lonend, Trinity, Edinburgh	
1878		* Kintore, the Right Hon. the Earl of, M.A., Cantab., Keith Hall, Inverurie, Aberdeenshire	
1875		* Kirkwood, Anderson, LL.D., 7 Melville Terrace, Stirling	
1880	P.	* Knott, C. G., D.Sc., Physical Laboratory, University of Edinburgh	195
1868		* Laidlay, J. W., of Seacliffe, North Berwick	
1875		* L'Amy, John Ramsay, of Dunkenny, Forfarshire, Aytoun Castle, 107 Cromwell Road, London, S.W.	
1878		* Lang, P. R. Scott, M.A., B.Sc., Professor of Mathematics in the University of St Andrews	
1870		* Laurie, Simon S., M.A., Professor of Education in the University of Edinburgh, Nairn Lodge, Duddingston	
1872		* Lee, H. Alexander, C.E., Blairhoyle, Stirling	200
1872		* Lee, the Hon. Lord, one of the Senators of the College of Justice, 26 Charlotte Square	
1863		* Leslie, Hon. G. Waldegrave, Leslie House, Leslie	
1858		* Leslie, James, Memb. Inst. Civil Engineers, 2 Charlotte Square	
1874	P.	* Letts, E. A., Ph.D., F.I.C., F.C.S., Professor of Chemistry, Queen's College, Belfast	
1861	N. P.	* Lindsay, W. Lauder, M.D., F.L.S., 9 Merchiston Avenue, Edinburgh	205
1864		* Lindsay, William, Hermitage-Hill House, Leith	
1870	B. P.	* Lister, Joseph, M.B., F.R.C.S.L., F.R.C.S.E., F.R.S., Professor of Clinical Surgery, 12 Park Crescent, Portland Place, London, N.W.	
1871		* Logie, Cosmo Garden, M.D., Surgeon-Major, Royal Horse Guards, 47 Queensborough Gardens, Bayswater	
1861	P.	* Lorimer, James, M.A., Advocate, Professor of Public Law in the University of Edinburgh, 1 Bruntsfield Crescent	
1849		Lowe, W. H., M.D., F.R.C.P.E., Mem. R.C.S. Eng., Wimbledon	210
1855		Macadam, Stevenson, Ph.D., 11 East Brighton Crescent, Portobello	
1867		* M'Candlish, John M., W.S., 4 Doune Terrace	
1866		* M'Culloch, John, 11 Duke Street	
1871		* Macdonald, Angus, M.D., F.R.C.P.E., F.R.C.S.E., 29 Charlotte Square	
1847		Macdonald, W. Macdonald, of St Martin's, Perth	215
1878		* MacDougall, Alan, Mem. Inst. Civil Engineers, Hobart House, Dalkeith	
1878	P.	* Macfarlane, Alexander, M.A., D.Sc., 25 Panmure Place	
1878		* M'Gowan, George, 24 Seton Place	
1880	P.	MacGregor, J. Gordon, M.A., D.Sc., Professor of Physics in Dalhousie College, Halifax, Nova Scotia	

Date of Election.			
1879		* M'Grigor, Alexander Bennett, LL.D., 19 Woodside Terrace, Glasgow	220
1869	N. P.	* M'Intosh, William Carmichael, M.D., LL.D., F.R.S., F.L.S., Murthly, Perthshire	
1873	P.	* M'Kendrick, John G., M.D., F.R.C.P.E., Professor of the Institutes of Medicine in the University of Glasgow	
1840		Mackenzie, John, New Club, Princes Street	
1877		* Macfie, Robert A., Dreghorn Castle, Colinton	
1843	P.	Maclagan, Douglas, M.D., F.R.C.P. and F.R.C.S.E., Professor of Medical Jurisprudence in the University of Edinburgh (VICE-PRESIDENT), 28 Heriot Row	225
1872		* Maclagan, David, C.A., 9 Royal Circus	
1853		Maclagan, General R., Royal Engineers, 37 Lexham Gardens, Kensington, W.	
1869		* Maclagan, R. Craig, M.D., 5 Coates Crescent	
1864		* M'Lagan, Peter, of Pumpherston, M.P., Linlithgow	
1869		* M'Laren, John, Q.C., Lord-Advocate of Scotland, 46 Moray Place	230
1870		* Macleod, George H. B., M.D., Professor of Surgery in the University of Glasgow, 10 Woodside Crescent, Glasgow	
1876		* Macleod, Rev. Norman, 7 Royal Circus	
1872		* Macmillan, Rev. Hugh, D.D., LL.D., Seafield, Greenock	
1876		* Macmillan, John, M.A., 18 Duncan Street, Drummond Place	
1866		* Macnair, John, 33 Moray Place	235
1877		* Macnee, Sir Daniel, K.C.B., President of the Royal Scot. Acad., 6 Learmonth Terrace	
1840	P.	M'Neill, The Right Hon. Sir John, G.C.B., K.L.S., LL.D., Burnhead, Liberton	
1858		* Malcolm, R. B., M.D., F.R.C.P.E., 126 George Street	
1880	P.	Marsden, R. Sydney, D.Sc., A.I.C., F.C.S., Tapton Grove, Sheffield	
1869		Marshall, Henry, M.D., Clifton, Bristol	240
1864		* Marwick, James David, LLD., Town-Clerk, Glasgow	
1866		* Masson, David, LL.D., Professor of Rhetoric and English Literature in the University of Edinburgh, 6 Minto Street	
1853		Mercer, Græme Reid, of Gorthie, Ceylon Civil Service	
1875		* Millar, C. H., of Blaircastle, 5 Palmerston Place	
1841		Miller, John, of Leithen, Memb. Inst. Civil Engineers, 2 Melville Crescent	245
1852		Miller, Thomas, M.A., LL.D., Rector of Perth Academy, Inchbank House, Perth	
1833		Milne, Admiral Sir Alexander, Bart., G.C.B., Inveresk	
1878		* Milne, John, Trinity Grove, Edinburgh	
1875		* Milroy, John, C.E., 8 Salisbury Road	
1866		* Mitchell, Arthur, M.A., M.D., LL.D., Commissioner in Lunacy, 34 Drummond Place	250
1843		Mitchell, Joseph, Memb. Inst. Civil Engineers, Viewhill, Inverness	
1879		* Moinet, Francis W., M.D., F.R.C.P.E., 13 Alva Street	
1865		* Moir, John J. A., M.D., F.R.C.P.E., 52 Castle Street	
1870		* Moncreiff, the Right Hon. Lord, of Tullibole, Lord Justice-Clerk, LL.D. (PRESIDENT), 15 Great Stuart Street	
1871		* Moncrieff, Rev. William Scott, of Fossaway, Bishop-Wearmouth, Sunderland	255
1868		* Montgomery, Very Rev. Dean, M.A., D.D., 17 Atholl Crescent	
1866		* Morehead, Charles, M.D., F.R.C.P.L., 11 North Manor Place	
1879		* Morrison, J. B. Brown, of Finderlie and Murie, Perthshire	
1877	P.	* Morrison, Robert Milner, D.Sc., F.I.C., Senior Demonstrator of Chemistry in the University of Edinburgh, 13 Douglas Crescent	
1861	P.	* Muir, John, D.C.L., LL.D., 10 Merchiston Avenue	260

Date of Election.			
1873		* Muir, M. M. Pattison, Prælector on Chemistry, Caius College, Cambridge	
1874	P.	* Muir, Thomas, M.A., High School, Glasgow	
1870		* Munn, David, High School	
1857		Murray, John Ivor, 8 Huntriss Row, Scarborough	
1877		* Murray, John, Challenger Expedition Office, 32 Queen Street	265
1877		* Napier, John, 23 Portman Square, London	
1874		* Napier, James, Maryfield House, Bothwell	
1866		* Nelson, Thomas, St Leonard's, Dalkeith Road	
1870	P.	* Nicholson, Henry Alleyne, M.D., D.Sc., President of the Royal Physical Society, Professor of Civil and Natural History in the University of St Andrews	
1880		* Nicol, W. W. J., M.A., 15 Blacket Place	270
1878		Norris, Richard, M.D., Professor of Physiology, Queen's College, Birmingham	
1877		Panton, George A., 38 Bennetts Hill, Birmingham	
1837	P.	Parnell, Richard, M.D., 17 Merchiston Avenue	
1863		* Peddie, Alexander, M.D., Vice-President of the Royal College of Physicians, Edinburgh, 15 Rutland Street	
1868		* Peddie, John Dick, M.P., Architect, 33 Buckingham Terrace	275
1869		Pender, John, M.P., Manchester	
1849		Pirrie, William, M.D., Professor of Surgery, Marischal College, Aberdeen	
1859	P.	* Playfair, The Right Hon. Lyon, C.B., M.P., LL.D., F.R.S., 68 Onslow Gardens, London	
1877		Pole, Wm., F.R.S., Mus. Doc., Mem. Inst. Civ. Eng., 31 Parliament St., Westminster, S.W.	
1874		Powell, Baden Henry Baden-, Forest Department, India	280
1852		Powell, Eyre B., C.S.I., M.A. Cantab., Victoria Villa, Weston Road, Bath	
1865		* Powrie, James, Reswallie, Forfar	
1880		* Prentice, Charles, Actuary, 8 St Bernard's Crescent	
1875		Prevost, E. W., Ph.D., Agricultural College, Cirencester	
1849		Primrose, Hon. B. F., C.B., 22 Moray Place	285
1873		Pritchard, Andrew, 87 St Paul's Road, Highbury, London	
1880		* Pullar, Robert, St Leonard's Bank, Perth	
1868		* Raleigh, Samuel, C.A., Park House, Dick Place	
1869		Raven, Rev. Thomas Milville, M.A., The Vicarage, Crakehall, Bedale	
1865		* Redford, Rev. Francis, M.A., The Rectory, Silloth	290
1836		Rhind, David, Architect, 19 Hill Street	
1875		* Richardson, Ralph, W.S., 38 Heriot Row	
1872		Ricarde-Lever, Major F. Ignacio, Carlton Club, St James' Street, London	
1877		* Roberton, James, LL.D., Professor of Conveyancing in the University of Glasgow, 1 Park Terrace East, Glasgow	
1880		Roberts, D. Lloyd, M.D., F.R.C.P.L., 23 St John Street, Manchester	295
1879		* Robertson, Major-General A. Cuningham, 86 Great King Street	
1872		* Robertson, D. M. C. L. Argyll, M.D., F,R.C.S.E., 18 Charlotte Square	
1859		* Robertson, George, Memb. Inst. Civil Engineers, 47 Albany Street	
1860		* Robertson, William, M.D., F.R.C.P.E., 28 Albany Street	
1877	P.	* Robinson, George Carr, F.I.C., Lecturer on Chemistry, Royal Institution, Hull	300
1862	P.	* Ronalds, Edmund, LL.D., Bonnington House, Bonnington Road, Edinburgh	
1880		* Ross, Donald, M.A., H.M. Inspector of Schools, Kilmalcolm, by Greenock	

Date of Election.			
1880		Rowland, L. L., M.A., M.D., President of the Oregon State Medical Society, and Professor of Physiology and Microscopy in Williamette University, Salem, Oregon	
1852	P.	Russell, Alexander James, C.S., 9 Shandwick Place	
1880		* Russell, J. A., M.A., B.Sc., M.B., Woodville, Canaan Lane, Edinburgh	305
1837	K.P.	Russell, John Scott, M.A., F.R.S., 5 Westminster Chambers, London	
1869	P.	* Rutherford, Wm., M.D., F.R.C.P.E., F.R.S., Professor of the Institutes of Medicine in the University of Edinburgh, 14 Douglas Crescent	
1870		* Sanders, William R., M.D., F.R.C.P.E., Professor of General Pathology in the University of Edinburgh, 30 Charlotte Square	
1863		* Sanderson, James, Deputy Inspector General of Hospitals, 41 Manor Place	
1864		* Sandford, Rev. D. F., LL.D., 6 Rutland Square	310
1849	P.	Sang, Edward, C.E., 6 Mollendo Terrace, Secretary to Royal Scottish Society of Arts	
1846		Schmitz, Leonard, LL.D., Belsize Park Gardens, London	
1880		Scott, J. H., M.B., C.M., M.R.C.S., Professor of Anatomy in the University of Otago, New Zealand	
1875		Scott, Michael, Memb. Inst. Civil Engineers, 9 Great Queen Street, Westminster, London	
1864		* Sellar, W.Y., M.A., LL.D., Professor of Humanity in the University of Edinburgh, 15 Buckingham Terrace	315
1872		* Seton, George, M.A. Oxon., Advocate, 42 Greenhill Gardens	
1872		* Sibbald, John, M.D., Commissioner in Lunacy, 3 St Margaret's Road, Whitehouse Loan	
1870		* Sime, James, M.A., Craigmount House, Dick Place	
1871		* Simpson, A. R., M.D., F.R.C.P.E., Professor of Midwifery in the University of Edinburgh, 52 Queen Street	
1859	P.	* Skene, William F., W.S., LL.D., D.C.L., 27 Inverleith Row	320
1876		* Skinner, William, W.S., Town-Clerk of Edinburgh, 35 George Square	
1868		* Smith, Adam Gillies, C.A. (TREASURER), 64 Princes Street	
1839		Smith, David, W.S., 10 Eton Terrace	
1871		* Smith, John, M.D., F.R.C.S.E., 11 Wemyss Place	
1863	P.	* Smith, John Alexander, M.D., F.R.C.P.E., 10 Palmerston Place	325
1855		Smith, R. M., 4 Bellevue Crescent	
1871	P.	* Smith, Rev. W. Robertson, M.A., Professor of Hebrew, Free Church College, Aberdeen, 83 Crown Street, Aberdeen	
1880		Smith, W. Robert, M.D., 15 Imperial Square, Cheltenham	
1846	K.P.	Smyth, Piazzi, Professor of Practical Astronomy, in the University of Edinburgh, and Astronomer-Royal for Scotland, 15 Royal Terrace	
1880		Sollas, W. J., M.A. Cantab., Lecturer on Geology in University College, Bristol	330
1866		* Spence, James, F.R.C.S.E., Professor of Surgery, 21 Ainslie Place	
1874	P.	* Sprague, T. B., M.A., 29 Buckingham Terrace	
1850	P.	Stark, James, M.D., F.R.C.P.E., of Huntfield, Biggar	
1844		Stevenson, David, Memb. Inst. Civil Engineers, 45 Melville Street	
1877		* Stevenson, James, F.R.G.S., 4 Woodside Crescent, Glasgow	335
1868		Stevenson, John J., Red House, Bayswater Hill, London, W.	
1848	P.	Stevenson, Thomas, Memb. Inst. Civ. Engineers, F.G.S., 17 Heriot Row	
1868		Stewart, Colonel J. H. M. Shaw, Royal Engineers, Madras	
1878		* Stewart, James R., M.A. Oxon., 10 Minto Street	
1866		* Stewart, T. Grainger, M.D., F.R.C.P.E., Professor of the Practice of Physic in the University of Edinburgh, 19 Charlotte Square	340

Date of Election.			
1873		* Stewart, Walter, 22 Torphichen Street	
1848		Stirling, Patrick J., LL.D., Kippendavie House, Dunblane	
1877		* Stirling, Wm., M.D., Sc.D., Professor of Institutes of Medicine in the University of Aberdeen	
1823		Stuart, Captain T. D., H.M.I.S.	
1870		* Swan, Patrick Don, Provost of Kirkcaldy	345
1848	P.	Swan, William, LL.D., Emeritus Professor of Natural Philosophy in the University of St Andrews	
1844		Swinton, A. Campbell, of Kimmerghame, LL.D., Dunse	
1875		* Syme, James, 10 Buckingham Terrace	
1872		Tait, the Rev. A., LL.D., Canon of Tuam, Moylough Rectory, Ballinasloe, Ireland	
1861	K.P.	* Tait, P. Guthrie, M.A., Professor of Natural Philosophy in the University of Edinburgh (GENERAL SECRETARY), 38 George Square	350
1870		* Tatlock, Robert R., City Analyst's Office, 138 Bath Street, Glasgow	
1846		Taylor, Sir Alexander, M.D., Pau, France	
1872		* Teape, Rev. Charles R., M.A., Ph.D., 15 Findhorn Place	
1873		* Tennent, Robert, F.M.S., 23 Buckingham Terrace	
1843		Thomson, Allen, M.D., F.R.C.S.E., F.R.S., Emeritus Professor of Anatomy in the University of Glasgow, 66 Palace Garden Terrace, London, W.	355
1870		* Thomson, Rev. Andrew, D.D., 63 Northumberland Street	
1875		* Thomson, James, LL.D., F.R.S., Professor of Engineering in the University of Glasgow, Oakfield House, University Avenue, Glasgow	
1880		Thomson, John Millar, King's College, London, W.C.	
1863		* Thomson, Murray, M.D., Professor of Chemistry, Thomason College, Roorkee, India	
1870		* Thomson, Spencer C., Actuary, 10 Chester Street	360
1855		Thomson, Sir C. Wyville, LL.D., F.R.S., Regius Professor of Natural History in the University of Edinburgh (VICE-PRESIDENT), Bonsyde, Linlithgow	
1847	K.P.	Thomson, Sir William, LL.D., D.C.L., F.R.S. (Hon. VICE-PRESIDENT), Regius Professor of Natural Philosophy in the University of Glasgow, Foreign Associate of the Institute of France	
1870		* Thomson, William Burns, F.R.C.P.E., F.R.C.S.E., 1 Ramsay Gardens	
1849		Thomson, William Thomas, Actuary, 27 Royal Terrace	
1876		Thomson, William, Royal Institution, Manchester	365
1878		Thorburn, Robert Macfie, Uddevalla, Sweden	
1874	N.P.	* Traquair, R. H., M.D., Keeper of the Natural History Collections in the Museum of Science and Art, Edinburgh, 8 Dean Park Crescent	
1874		* Tuke, J. Batty, M.D., F.R.C.P.E., 20 Charlotte Square	
1879		* Turnbull, John, of Abbey St Bathans, W.S., 49 George Square	
1867		* Turnbull, William, Menslaws, Jedburgh	370
1861	N.P.	* Turner, William, M.B., F.R.C.S.E., F.R.S., Professor of Anatomy in the University of Edinburgh, (SECRETARY), 6 Eton Terrace	
1877		* Underhill, Charles E., B.A., M.B., F.R.C.P.E., F.R.C.S.E., 8 Coates Crescent	
1875		Vincent, Charles Wilson, Royal Institution, Albemarle Street, London	
1867		* Waddell, Peter, 5 Claremont Park, Leith	
1829		Walker, James, W.S., Tunbridge Wells	375
1873		* Walker, Robert, M.A., University, Aberdeen	

Date of Election.			
1864		* Wallace, William, Ph.D., City Analyst's Office, 138 Bath Street, Glasgow	
1870		* Watson, James, 45 Charlotte Square	
1866		* Watson, John K., 14 Blackford Road	
1873	P.	* Watson, Morrison, M.D., F.R.C.P.E., Professor of Anatomy, Owens College, Manchester	380
1866		* Watson, Patrick Heron, M.D., F.R.C.P.E., F.R.C.S.E., 16 Charlotte Square	
1862	P.	Watson, Rev. Robert Boog, Free Church Manse, Cardross, Dumbartonshire	
1877		Weldon, Walter, F.C.S., Rede Hall, Burstow, Surrey	
1873		Welsh, Major, Bengal Artillery	
1840		Welwood, Allan A. Maconochie, LL.D., of Meadowbank and Garvoch, Kirknewton	385
1876		White, Rev. Francis Le Grix, M.A., F.R. Hist. S., F.G.S., Leaming House, Ulleswater, Penrith, Cumberland	
1879		* Will, John Charles Ogilvie, M.D., 12 Union Terrace, Aberdeen	
1868		* Williams, W., Principal and Professor of Veterinary Medicine and Surgery, New Veterinary College, Gayfield House	
1858		* Williamson, Thomas, M.D., F.R.C.S.E., 28 Charlotte Street, Leith	
1879		* Wilson, Andrew, Ph.D., Lecturer on Zoology and Comparative Anatomy in the Edinburgh Medical School, 118 Gilmore Place	390
1877		* Wilson, Charles E., M.A., LL.D., H. M. Senior Inspector of Schools, 19 Palmerston Pl.	
1878		* Wilson, Rev. John, M.A., Bannockburn Academy	
1875		Wilson, Daniel, LL.D., Professor of English Literature in the University of Toronto	
1834		Wilson, Isaac, M.D.	
1847		Wilson, John, Professor of Agriculture in the University of Edinburgh	395
1863		* Wilson, J. G., M.D., F.R.C.S.E., 9 Woodside Crescent, Glasgow	
1873		Wilson, Robert, Engineer, Patricroft, Manchester	
1870		Winzer, John, Chief Surveyor, Civil Service, Ceylon, 7 Dryden Place, Newington, Edinburgh	
1880		Wise, Thomas Alexander, M.D., F.R.C.P.E., Thornton, Beulah Hill, Upper Norwood, Surrey	
1864		* Wood, Alexander, M.D., F.R.C.P.E., 12 Strathearn Place	400
1864		* Wood, Andrew, M.D., F.R.C.S.E., 9 Darnaway Street	
1855		Wright, Thomas, M.D., F.R.S., Cheltenham	
1864		* Wyld, Robert S., LL.D , 19 Inverleith Row	
1861		* Young, James, of Kelly and Durris, F.R.S., Wemyss Bay, by Greenock	404

LIST OF HONORARY FELLOWS

AT JANUARY 1881.

His Royal Highness the PRINCE OF WALES.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.)

Elected.		
1864	Robert Wilhelm Bunsen,	*Heidelberg.*
1867	Michel Eugène Chevreul,	*Paris.*
1858	James D. Dana,	*New Haven, Connecticut, United States.*
1877	Alphonse De Candolle,	*Geneva.*
1879	Franz Cornelius Donders,	*Utrecht.*
1855	Jean Baptiste Dumas,	*Paris.*
1877	Carl Gegenbaur,	*Heidelberg.*
1879	Asa Gray,	*Harvard University, Cambridge, United States.*
1864	Hermann Ludwig Ferdinand Helmholtz,	*Berlin.*
1879	Jules Janssen,	*Paris.*
1875	August Kekulé,	*Bonn.*
1868	Gustav Robert Kirchhoff,	*Berlin.*
1875	Herman Kolbe,	*Leipzig.*
1864	Albert Kölliker,	*Würzburg.*
1875	Ernst Eduard Kummer,	*Berlin.*
1864	Richard Lepsius,	*Berlin.*
1876	Ferdinand de Lesseps,	*Paris.*
1864	Rudolph Leuckart,	*Leipzig.*
1879	Johann Benedict Listing,	*Göttingen.*
1875	Joseph Liouville,	*Paris.*
1881	Sven Lovén,	*Stockholm.*
1876	Carl Ludwig,	*Leipzig.*
1878	J. N. Madvig,	*Copenhagen.*
1855	Henry Milne-Edwards,	*Paris.*
1864	Theodore Mommsen,	*Berlin.*
1881	Simon Newcomb,	*Washington.*
1874	Louis Pasteur,	*Paris.*
1881	Émile Plantamour,	*Geneva.*
1864	Karl Theodor von Siebold,	*Munich.*
1881	Johannes Iapetus Smith Steenstrup,	*Copenhagen.*
1878	Otto Wilhelm Struve,	*Pulkowa, St Petersburg.*
1855	Bernard Studer,	*Berne.*
1874	Otto Torell,	*Lund.*
1868	Rudolph Virchow,	*Berlin.*
1874	Wilhelm Eduard Weber,	*Göttingen.*
1867	Friedrich Wöhler,	*Do.*

Total, 36.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.)

Elected.		
1849	John Couch Adams, LL.D., F.R.S., Mem. Inst. France,	*Cambridge.*
1835	Sir George Biddell Airy, K.C.B., M.A., D.C.L., LL.D., F.R.S.,	*Greenwich.*
1870	Thomas Andrews, M.D., LL.D., F.R.S.,	*Belfast* (*Queen's College*).
1866	Thomas Carlyle, LL.D., Ord. Boruss. "Pour le Mérite," Pres. Phil. Inst. Edin.,	*London.*
1865	Arthur Cayley, LL.D., F.R.S., Mem. Inst. France,	*Cambridge.*
1865	Charles Darwin, M.A., F.R.S., Mem. Inst. France,	*Down, Bromley, Kent.*
1874	John Anthony Froude, LL.D.,	*London.*
1881	The Hon. Justice Grove, M.A., D.C.L., LL.D.,	*Do.*
1876	Thomas Henry Huxley, D.C.L., LL.D., Sec. R.S., Mem. Inst. France,	*Do.*
1867	James Prescott Joule, LL.D., D.C.L., F.R.S., Mem. Inst. France,	12 *Wardle Road, Sale near Manchester.*
1845	Richard Owen, C.B., M.D., LL.D., D.C.L., F.R.S., Mem. Inst. France,	*London.*
1876	Thomas Romney Robinson, D.D., LL.D., D.C.L., F.R.S., M.R.I.A.,	*Armagh.*
1865	General Sir Edward Sabine, R.A., K.C.B., LL.D., D.C.L., F.R.S., Mem. Inst. France,	*London.*
1881	The Rev. George Salmon, D.D., D.C.L., LL.D.,	*Trinity College, Dublin.*
1876	Henry John Stephen Smith, M.A., LL.D., F.R.S., F.C.S.,	*Oxford.*
1878	Balfour Stewart, M.A., LL.D., F.R.S.,	*Manchester.*
1864	George Gabriel Stokes, M.A., LL.D., D.C.L., Sec. R.S., Mem. Inst. France,	*Cambridge.*
1874	James Joseph Sylvester, M.A., LL.D., F.R.S., Mem. Inst. France,	*Baltimore, United States.*
1864	Alfred Tennyson, D.C.L., F.R.S., Poet Laureate,	*Freshwater, Isle of Wight.*

Total, 19.

LIST OF ORDINARY FELLOWS.

Elected from July 1879 *to November* 1880, *arranged according to the date of their Election.*

7th July 1879.

JOHN CALDERWOOD, F.I.C.

JOHN CHARLES OGILVIE WILL, M.D.

5th January 1880.

THOMAS ARMSTRONG ELLIOT, M.A.

2d February 1880.

Professor GEORGE CHRYSTAL.

GEORGE RITCHIE GILRUTH, L.R.C.S.E.

D. LLOYD ROBERTS, F.R.C.P.L.

A. H. JAPP, LL.D.

DONALD ROSS.

1st March 1880.

J. M. THOMSON.

C. G. KNOTT, D.Sc.

J. A. RUSSELL, M.A.

W. W. J. NICOL, M.A.

CHARLES PRENTICE, C.A.

L. L. ROWLAND, M.A., M.D.

ROBERT PULLAR.

Professor ROBERT FLINT, D.D.

DE BURGH BIRCH, M.B., C.M.

J. BERRY HAYCRAFT, M.B., B.Sc.

5th April 1880.

Major-General JOHN BAYLY, R.E.

W. J. SOLLAS, M.A.

HENRY DRUMMOND, F.G.S.

3d May 1880.

Professor J. H. SCOTT.

JAMES GRAHAM.

R. SYDNEY MARSDEN, D.Sc.

7th June 1880.

WILLIAM F. KING.

Professor JAMES GORDON MACGREGOR.

PATRICK GEDDES.

W. ROBERT SMITH, M.D.

LIST OF FELLOWS DECEASED, RESIGNED, AND CANCELLED.

HONORARY FELLOWS (BRITISH) DECEASED.

From June 1879 to January 1881.

William Lassell, F.R.S.
William Hallowes Miller, F.R.S.
Rev. Dr Humphrey Lloyd.

HONORARY FELLOWS (FOREIGN) DECEASED.

From June 1879 to January 1881.

Heinrich Wilhelm Dove.
Johann von Lamont.
Professor Benjamin Peirce.

ORDINARY FELLOWS DECEASED.

From November 1878 to November 1879.

Alexander J. Adie.
John Blackwood.
Dr Thomas R. Colledge.
E. W. Dallas.
Dr J. G. Fleming.
Edward J. Jackson.
Professor Kelland, F.R.S.
Dr James M'Bain.
Professor James Clerk-Maxwell, F.R.S
Professor Nicol.
Dr Montgomerie Rorertson.
J. F. Rodger.
Dr John Smith.
Sir Walter C. Trevelyan.
Arthur, Marquis of Tweeddale, F.R.S.

From November 1879 to November 1880.

Thomas Key.
Thomas Knox.
Maurice Lothian.
The Hon. Lord Ormidale.
Mungo Ponton.
Dr Sharpey, F.R.S.

FELLOWS RESIGNED.

Session 1878–79.

Professor Fuller.
Professor John Young, M.D.
O. G. Miller.

During Session 1879–80.

Dr A. Bruce Bremner.
David MacGibbon.
Professor J. Bell Pettigrew, F.R.S.

LAWS

OF THE

ROYAL SOCIETY OF EDINBURGH,

AS REVISED 19TH JANUARY 1880.

LAWS.

[By the Charter of the Society (printed in the *Transactions*, Vol. VI. p. 5), the Laws cannot be altered, except at a Meeting held one month after that at which the Motion for alteration shall have been proposed.]

I.

Title.

THE ROYAL SOCIETY OF EDINBURGH shall consist of Ordinary and Honorary Fellows.

II.

The fees of Ordinary Fellows residing in Scotland.

Every Ordinary Fellow, within three months after his election, shall pay Two Guineas as the fee of admission, and Three Guineas as his contribution for the Session in which he has been elected; and annually at the commencement of every Session, Three Guineas into the hands of the Treasurer. This annual contribution shall continue for ten years after his admission, and it shall be limited to Two Guineas for fifteen years thereafter.*

III.

Payment to cease after 25 years.

All Fellows who shall have paid Twenty-five years' annual contribution shall be exempted from farther payment.

IV.

Fees of Non-Resident Ordinary Fellows.

The fees of admission of an Ordinary Non-Resident Fellow shall be £26, 5s., payable on his admission; and in case of any Non-Resident Fellow coming to reside at any time in Scotland, he shall, during each year of his residence, pay the usual annual contribution of £3, 3s., payable by each Resident Fellow; but after payment of such annual contribution for eight years, he shall be exempt

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* At the Meeting of the Society, on the 5th January 1857, when the reduction of the Contributions from £3, 3s., to £2, 2s., from the 11th to the 25th year of membership, was adopted, it was resolved that the existing Members shall share in this reduction, so far as regards their future annual Contributions.

A modification of this rule, in certain cases, was agreed to 3d January 1831.

se of Fellows oming Non-Re- ent.

from any farther payment. In the case of any Resident Fellow ceasing to reside in Scotland, and wishing to continue a Fellow of the Society, it shall be in the power of the Council to determine on what terms, in the circumstances of each case, the privilege of remaining a Fellow of the Society shall be continued to such Fellow while out of Scotland.

V.

faulters.

Members failing to pay their contributions for three successive years (due application having been made to them by the Treasurer) shall be reported to the Council, and, if they see fit, shall be declared from that period to be no longer Fellows, and the legal means for recovering such arrears shall be employed.

VI.

vileges of linary Fellows.

None but Ordinary Fellows shall bear any office in the Society, or vote in the choice of Fellows or Office-Bearers, or interfere in the patrimonial interests of the Society.

VII.

mbers Un- ited.

The number of Ordinary Fellows shall be unlimited.

VIII.

llows entitled Transactions.

The Ordinary Fellows, upon producing an order from the TREASURER, shall be entitled to receive from the Publisher, gratis, the Parts of the Society's Transactions which shall be published subsequent to their admission.

IX.

ode of Recom- nding Ordinary llows

Candidates for admission as Ordinary Fellows shall make an application in writing, and shall produce along with it a certificate of recommendation to the purport below,* signed by at least *four* Ordinary Fellows, two of whom shall certify their recommendation from personal knowledge. This recommendation shall be delivered to the Secretary, and by him laid before the Council, and shall afterwards be printed in the circulars for three Ordinary Meetings of the Society, previous to the day of election, and shall lie upon the table during that time.

* "A. B., a gentleman well versed in Science (*or Polite Literature, as the case may be*), being "to our knowledge desirous of becoming a Fellow of the Royal Society of Edinburgh, we hereby "recommend him as deserving of that honour, and as likely to prove a useful and valuable Member."

X.

Honorary Fellows, British and Foreign.

Honorary Fellows shall not be subject to any contribution. This class shall consist of persons eminently distinguished for science or literature. Its number shall not exceed Fifty-six, of whom Twenty may be British subjects, and Thirty-six may be subjects of foreign states.

XI.

Royal Personages

Personages of Royal Blood may be elected Honorary Fellows, without regard to the limitation of numbers specified in Law X.

XII.

Recommendation of Honorary Fellows.

Honorary Fellows may be proposed by the Council, or by a recommendation (in the form given below*) subscribed by three Ordinary Fellows; and in case the Council shall decline to bring this recommendation before the Society, it shall be competent for the proposers to bring the same before a General Meeting. The election shall be by ballot, after the proposal has been communicated *viva voce* from the Chair at one meeting, and printed in the circulars for two ordinary meetings of the Society, previous to the day of election.

Mode of Election.

XIII.

Election of Ordinary Fellows.

The election of Ordinary Fellows shall only take place at the first Ordinary Meeting of each month during the Session. The election shall be by ballot, and shall be determined by a majority of at least two-thirds of the votes, provided Twenty-four Fellows be present and vote.

XIV.

Ordinary Meetings.

The Ordinary Meetings shall be held on the first and third Mondays of every month from November to June inclusively. Regular Minutes shall be kept of the proceedings, and the Secretaries shall do the duty alternately, or according to such agreement as they may find it convenient to make.

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* We hereby recommend ______________________________
for the distinction of being made an Honorary Fellow of this Society, declaring that each of us from our own knowledge of his services to (*Literature or Science, as the case may be*) believe him to be worthy of that honour.

(To be signed by three Ordinary Fellows.)

____

____

____

To the President and Council of the Royal Society
of Edinburgh.

XV.

e Transactions.

The Society shall from time to time publish its Transactions and Proceedings. For this purpose the Council shall select and arrange the papers which they shall deem it expedient to publish in the *Transactions* of the Society, and shall superintend the printing of the same.

The Council shall have power to regulate the private business of the Society. At any Meeting of the Council the Chairman shall have a casting as well as a deliberative vote.

XVI.

w Published.

The Transactions shall be published in parts or *Fasciculi* at the close of each Session, and the expense shall be defrayed by the Society.

XVII.

e Council.

That there shall be formed a Council, consisting—First, of such gentlemen as may have filled the office of President; and Secondly, of the following to be annually elected, viz.—a President, Six Vice-Presidents (two at least of whom shall be resident), Twelve Ordinary Fellows as Councillors, a General Secretary, Two Secretaries to the Ordinary Meetings, a Treasurer, and a Curator of the Museum and Library.

XVIII.

etiring Council-
rs.

Four Councillors shall go out annually, to be taken according to the order in which they stand on the list of the Council.

XIX.

lection of Office-
earers.

An Extraordinary Meeting for the Election of Office-Bearers shall be held on the fourth Monday of November annually.

XX.

pecial Meetings;
w called.

Special Meetings of the Society may be called by the Secretary, by direction of the Council; or on a requisition signed by six or more Ordinary Fellows. Notice of not less than two days must be given of such Meetings.

XXI.

reasurer's Duties.

The Treasurer shall receive and disburse the money belonging to the Society, granting the necessary receipts, and collecting the money when due.

He shall keep regular accounts of all the cash received and expended, which shall be made up and balanced annually; and at the Extraordinary Meeting in November, he shall present the accounts for the preceding year, duly audited.

At this Meeting, the Treasurer shall also lay before the Council a list of all arrears due above two years, and the Council shall thereupon give such directions as they may deem necessary for recovery thereof.

XXII.

Auditor.

At the Extraordinary Meeting in November, a professional accountant shall be chosen to audit the Treasurer's accounts for that year, and to give the necessary discharge of his intromissions.

XXIII.

General Secretary's Duties.

The General Secretary shall keep Minutes of the Extraordinary Meetings of the Society, and of the Meetings of the Council, in two distinct books. He shall, under the direction of the Council, conduct the correspondence of the Society, and superintend its publications. For these purposes he shall, when necessary, employ a clerk, to be paid by the Society.

XXIV.

Secretaries to Ordinary Meetings.

The Secretaries to the Ordinary Meetings shall keep a regular Minute-book, in which a full account of the proceedings of these Meetings shall be entered; they shall specify all the Donations received, and furnish a list of them, and of the Donors' names, to the Curator of the Library and Museum; they shall likewise furnish the Treasurer with notes of all admissions of Ordinary Fellows. They shall assist the General Secretary in superintending the publications, and in his absence shall take his duty.

XXV.

Curator of Museum and Library.

The Curator of the Museum and Library shall have the custody and charge of all the Books, Manuscripts, objects of Natural History, Scientific Productions, and other articles of a similar description belonging to the Society; he shall take an account of these when received, and keep a regular catalogue of the whole, which shall lie in the Hall, for the inspection of the Fellows.

XXVI.

Use of Museum and Library.

All Articles of the above description shall be open to the inspection of the Fellows at the Hall of the Society, at such times and under such regulations, as the Council from time to time shall appoint.

XXVII.

Register Book.

A Register shall be kept, in which the names of the Fellows shall be enrolled at their admission, with the date.

THE KEITH, BRISBANE, AND NEILL PRIZES.

The above Prizes will be awarded by the Council in the following manner :—

I. KEITH PRIZE.

The Keith Prize, consisting of a Gold Medal and from £40 to £50 in Money, will be awarded in the Session 1881–82, for the "best communication on a scientific subject, communicated, in the first instance, to the Royal Society during the Sessions 1879–80 and 1880–81." Preference will be given to a paper containing a discovery.

II. MAKDOUGALL-BRISBANE PRIZE.

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded at the commencement of the Session 1882–83, for an Essay or Paper having reference to any branch of scientific inquiry, whether Material or Mental.

2. Competing Essays to be addressed to the Secretary of the Society, and transmitted not later than 1st June 1882.

3. The Competition is open to all men of science.

4. The Essays may be either anonymous or otherwise. In the former case, they must be distinguished by mottoes, with corresponding sealed billets superscribed with the same motto, and containing the name of the Author.

5. The Council impose no restriction as to the length of the Essays, which may be, at the discretion of the Council, read at the Ordinary Meetings of the Society. They wish also to leave the property and free disposal of the manuscripts to the Authors; a copy, however, being deposited in the Archives of the Society, unless the Paper shall be published in the Transactions.

6. In awarding the Prize, the Council will also take into consideration any scientific papers presented to the Society during the Sessions 1880–81 and 1881–82, whether they may have been given in with a view to the Prize or not.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr Patrick Neill of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate,

1. The Neill Prize, consisting of a Gold Medal and a sum of Money, will be awarded during the Session 1880–81.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented to the Society during the three years preceding the 1st May 1880,—or failing presentation of a paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award.

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, AND NEILL PRIZES, FROM 1827 TO 1879.

I. KEITH PRIZE.

1st Biennial Period, 1827–29.—Dr Brewster, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2d Biennial Period, 1829–31.—Dr Brewster, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3d Biennial Period, 1831–33.—Thomas Graham, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4th Biennial Period, 1833–35.—Professor J. D. Forbes, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of the Society.

5th Biennial Period, 1835–37.—John Scott Russell, Esq., for his Researches "on Hydrodynamics," published in the Transactions of the Society.

6th Biennial Period, 1837–39.—Mr John Shaw, for his experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7th Biennial Period, 1839–41.—Not awarded.

8th Biennial Period, 1841–43.—Professor James David Forbes, for his Papers "on Glaciers," published in the Proceedings of the Society.

9th Biennial Period, 1843–45.—Not awarded.

10th Biennial Period, 1845–47.—General Sir Thomas Brisbane, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11th Biennial Period, 1847–49.—Not awarded.

12th Biennial Period, 1849–51.—Professor Kelland, for his papers "on General Differentiation, including his more recent communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13th Biennial Period, 1851–53.—W. J. Macquorn Rankine, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14th Biennial Period, 1853–55.—Dr Thomas Anderson, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15th Biennial Period, 1855–57.—Professor Boole, for his Memoir "on the Application of the Theory of Probabilities to Questions of the Combination of Testimonies and Judgments," published in the Transactions of the Society.

16th Biennial Period, 1857–59.—Not awarded.

17th Biennial Period, 1859–61.—John Allan Broun, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on the Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18th Biennial Period, 1861–63.—Professor William Thomson, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems."

19th Biennial Period, 1863–65.—Principal Forbes, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society,

20th Biennial Period, 1865–67.—Professor C. Piazzi Smyth, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21st Biennial Period, 1867–69.—Professor P. G. Tait, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22d Biennial Period, 1869–71.—Professor Clerk Maxwell, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

23d Biennial Period, 1871–73.—Professor P. G. Tait for his paper entitled "First Approximation to a Thermo-electric Diagram," published in the Transactions of the Society.

24th Biennial Period, 1873–75.—Professor Crum Brown, for his Researches "on the sense of Rotation, and on the Anatomical Relations of the Semicircular Canals of the Internal Ear."

25th Biennial Period, 1875–77.—Professor M. Forster Heddle, for his papers "on the Rhombohedral Carbonates," and "on the Felspars of Scotland," published in the Transactions of the Society.

26th Biennial Period, 1877–79.—Professor H. C. Fleeming Jenkin, for his paper "on the Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in the Transactions of the Society; Part II. having appeared in the volume for 1877–78.

II. MAKDOUGALL-BRISBANE PRIZE.

1st Biennial Period, 1859.—Sir Roderick Impey Murchison, on account of his Contributions to the Geology of Scotland.

2d Biennial Period, 1860–62.—William Seller, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3d Biennial Period, 1862–64.—John Denis Macdonald, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as Two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4th Biennial Period, 1864–66.—Not awarded.

5th Biennial Period, 1866–68.—Dr **Alexander Crum Brown** and Dr **Thomas Richard Fraser**, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6th Biennial Period, 1868–70.—Not awarded.

7th Biennial Period, 1870–72.—**George James Allman**, M.D., F.R.S., Emeritus Professor of Natural History, for his paper "on the Homological Relations of the Cœlenterata," published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

8th Biennial Period, 1872–74.—Professor **Lister**, for his paper "on the Germ Theory of Putrefaction and the Fermentative Changes," communicated to the Society 7th April 1873.

9th Biennial Period, 1874–76.—**Alexander Buchan**, A.M., for his paper "on the Diurnal Oscillation of the Barometer," published in the Transactions of the Society.

10th Biennial Period, 1876–78.—Professor **Archibald Geikie**, for his paper "on the Old Red Sandstone of Western Europe," published in the Transactions of the Society.

III. THE NEILL PRIZE.

1st Triennial Period, 1856–59.—Dr **W. Lauder Lindsay**, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2d Triennial Period, 1859–62.—**Robert Kaye Greville**, LL.D., for his Contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3d Triennial Period, 1862–65.—**Andrew Crombie Ramsay**, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various works and Memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the arduous work of the Geological Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4th Triennial Period, 1865–68.—Dr **William Carmichael M'Intosh**, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5th Triennial Period, 1868–71.—Professor **William Turner**, for his papers "on the great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

6th Triennial Period, 1871–74.—**Charles William Peach**, for his Contributions to Scottish Zoology and Geology, and for his recent contributions to Fossil Botany.

7th Triennial Period, 1874–77.—Dr **Ramsay H. Traquair**, for his paper "on the Structure and Affinities of *Tristichopterus alatus* (Egerton)," published in the Transactions of the Society, and also for his contributions to the Knowledge of the Structure of Recent and Fossil Fishes.

PROCEEDINGS

OF THE

STATUTORY GENERAL MEETINGS,

AND

LIST OF MEMBERS ELECTED AT THE ORDINARY MEETINGS

FROM NOVEMBER 1878 TO NOVEMBER 1880.

STATUTORY MEETINGS.

NINETY-SEVENTH SESSION.

Monday, 24th November 1879.

At a Statutory Meeting, David Stevenson, Esq., in the Chair, the Minutes of last General Statutory Meeting of 25th November 1878 were read, approved, and signed.

The Chairman explained that there was a feeling shared by many of the Fellows, that the President now to be elected should belong to the literary side of the Society.

He also read from the Minutes of Council Dr Balfour's resignation of the office of General Secretary, with the Council's expressions of regret.

A Ballot then took place for the new Council. Messrs George Robertson and Robert Cox were appointed Scrutineers. The following Council was elected:—

The Right Hon. Lord Moncreiff, President.
The Right Rev. Bishop Cotterill,
Principal Sir Alexander Grant, Bart.,
David Milne Home, LL.D.,
Sir C. Wyville Thomson, LL.D.,
Professor Douglas Maclagan, M.D.,
Professor H. C. Fleeming Jenkin, F.R.S.
} Vice-Presidents.
Professor Tait, General Secretary.
Professor Turner,
Professor Crum Brown,
} Secretaries to Ordinary Meetings.
David Smith, Esq., Treasurer.
Alexander Buchan, M.A., Curator of Library and Museum.

COUNCILLORS.

Professor Rutherford.
Dr R. M. Ferguson.
Rev. W. Lindsay Alexander, D.D.
Dr Thomas A. G. Balfour.
J. Y. Buchanan, M.A.
Rev. Thomas Brown.
Robert Gray.
Dr William Robertson.
Professor Campbell Fraser.
Professor Geikie.
Rev. Dr Cazenove.
David Stevenson, M.I.C.E.

The Treasurer's Accounts were submitted and approved.

Mr George Robertson moved the appointment of Mr Auldjo Jamieson as Auditor, which was agreed to.

Dr Lindsay Alexander and Mr David Stevenson were appointed a Committee to prepare for next Ordinary Meeting of the Society an expression of the loss the Society has suffered by the resignation of Professor Balfour.

Professor Turner gave notice of the following motions:—

> "That the Honorary Vice-Presidents be in future members of the Council of the Royal Society, and that the Laws of the Society be modified to the extent necessary to carry this into effect."
>
> "That the Chairman of the Meetings of the Council should have a casting as well as a deliberative vote"

In accordance with the Laws, these Notices will be inserted in the Billets for the Ordinary Meetings till January 5th inclusive, when they will be voted upon.

The Secretary reported that the number of Ordinary Fellows was 385.

NINETY-EIGHTH SESSION.

Monday, 22d November 1880.

At a Statutory Meeting, Professor MACLAGAN, Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 24th November 1879 were read, approved, and signed.

Dr J. C. OGILVIE WILL was admitted to the Society, and signed the Laws.

The Chairman requested the Rev. THOMAS BROWN and Mr GEORGE FORBES to act as Scrutineeers.

Before the Ballot the Secretary requested instructions as to ballot papers which had been forwarded to him by post. After an explanation from Dr J. H. BALFOUR, it was decided that these papers were not admissible.

The Ballot for the new Council then took place. The following Council was elected:—

The Right Hon. LORD MONCREIFF, President.
Principal Sir ALEXANDER GRANT, Bart., } Vice-Presidents.
DAVID MILNE HOME, LL.D., } Vice-Presidents.
Sir C. WYVILLE THOMSON, LL.D., } Vice-Presidents.
Professor DOUGLAS MACLAGAN, M.D., } Vice-Presidents.
Professor H. C. FLEEMING JENKIN, F.R.S., } Vice-Presidents.
Rev. W. LINDSAY ALEXANDER, D.D., } Vice-Presidents.
Professor TAIT, General Secretary.
Professor TURNER, } Secretaries to Ordinary Meetings.
Professor CRUM BROWN, } Secretaries to Ordinary Meetings.
ADAM GILLIES SMITH, C.A., Treasurer.
ALEXANDER BUCHAN, M.A., Curator of Library and Museum.

COUNCILLORS.

J. Y. BUCHANAN, M.A.
Rev. THOMAS BROWN.
ROBERT GRAY.
Dr WILLIAM ROBERTSON.
Professor CAMPBELL FRASER.
Professor GEIKIE.
Rev. Dr CAZENOVE.
DAVID STEVENSON, M.I.C.E.
Professor CHRYSTAL.
ALEXANDER FORBES IVRINE, of Drum.
Professor A. DICKSON.
The Right Rev. Bishop COTTERILL.

The TREASURER'S Accounts, audited, were submitted. On the motion of Mr PULLAR, seconded by the Rev. Dr CAZENOVE, the Accounts were approved.

Mr JAMIESON was reappointed Auditor.

It was moved by the VICE-PRESIDENT in the Chair, and carried by acclamation—

> "That the Royal Society desires to record its acknowledgment of the faithful and able manner in which Mr DAVID SMITH has, for the period of seventeen years, discharged the duties of Treasurer to the Society: That the Society votes its thanks to Mr SMITH for his long and successful services to it as its Treasurer: That an Excerpt from the Minutes recording the above resolutions be transmitted by the Secretary to Mr SMITH."

The SECRETARY reported the number of Ordinary Fellows as 402.

The following Public Institutions and Individuals are entitled to receive Copies of the Transactions and Proceedings of the Royal Society of Edinburgh:—

ENGLAND.

London, British Museum.
... Royal Society.
... Society of Antiquaries.
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... Chemical Society.
... Institution of Civil Engineers.
... Royal Geographical Society.
... Geological Society.
... Royal Horticultural Society.
... Hydrographic Office, Admiralty.
... Royal Institution.
... Linnean Society.
... Royal Society of Literature.
... Medico-Chirurgical Society.
... Royal Microscopical Society.
... Museum of Economic Geology.
... Royal Observatory, Greenwich.
... Statistical Society.
... Royal College of Surgeons of England.
... United Service Institution.
... Zoological Society.

Cambridge Philosophical Society.
... University Library.
Historic Society of Lancashire and Cheshire.
Leeds Philosophical and Literary Society.
Manchester Literary and Philosophical Society.
Oxford, Bodleian Library.
Yorkshire Philosophical Society.

SCOTLAND.

Edinburgh, Advocates' Library.
... University Library.
... College of Physicians.
... Highland and Agricultural Society.
. Royal Medical Society.
... Royal Physical Society.
... Royal Scottish Society of Arts.
... Royal Botanic Garden.
Aberdeen, University Library.
Glasgow, University Library.
St Andrews, University Library.

IRELAND.

Royal Dublin Society.
Royal Irish Academy.
Library of Trinity College, Dublin.

COLONIES, &C.

Calcutta, Asiatic Society.
Canada, Library of Geological Survey.
Cape of Good Hope, The Observatory.
Melbourne, University Library.
Toronto, Literary and Historical Society.
Sydney, University Library.
Wellington, Royal Society of New South Wales.
New Zealand Institute.

CONTINENT OF EUROPE.

Amsterdam, De Koninklijke Akademie van Wetenschappen.
Basle, Die Schweizerische Naturforschende Gesellschaft.
Berlin, Königliche Akademie der Wissenschaften.
... Physicalische Gessellschaft.
Bern, Allgemeine Schweizerische Gesellschaft für die gesammten Naturwissenschaften.
Bologna, Accademia delle Scienze dell' Istituto.
Bordeaux, Société des Sciences Physiques et Naturelles.
Brussels, Académie Royale des Sciences, des Lettres et des Beaux-Arts.
... L' Observatoire Royal.
... La Société Scientifique.
Buda, A Magyar Tudós Tarsasag—Die Ungarische Akademie der Wissenschaften.
Christiania, University Library.
Copenhagen, Royal Academy of Sciences.
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Ekatherinebourg, La Société Ouralienne d'Amateurs des Sciences Naturelles.
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Frankfurt-am-Main, Senckenbergische Naturforschende Gesellschaft.
Geneva, Société de Physique et d' Histoire Naturelle.
Genoa, Annali del Museo Civico di Storia Naturale.
Giessen, University Library.
Göttingen, University Library.
Graz, Naturwissenschaftlicher Verein für Steiermark.
Haarlem, Société Hollandaise des Sciences Exactes et Naturelles.
... Musée Teyler.
Halle, Kaiserliche Leopoldino - Carolinische deutsche Akademie der Naturforscher.
Helsingfors, Société pro Fauna et Flora Fennica.
... Societas Scientiarum Fennica (Société des Sciences de Finlande).
Java, Bataviaasch Genootschap van Kunsten en Wetenschappen.
... The Observatory.
Jena, Medicinisch-Naturwissenschaftliche Gesellschaft.
Kiel, University Library.
Leipzig, Prof. Wiedemann, Königliche Sächsische Akademie.
Lille, Société des Sciences.
Lisbon, Academia Real das Sciencias de Lisboa.
Louvain, University Library.
Lund, University Library.
Lyons, Academie des Sciences, Belles Lettres et Arts.
... Musée Guimet.
... Société d'Agriculture.
Madrid, Real Academia de Ciencias.
... Comision del Mapa Geologico de España.
Milan, Reale Istituto Lombardo di Scienze, Lettere, ed Arti.
Modena, Regia Accademia di Scienze, Lettere, ed Arti.
Montpellier, Academie des Sciences et Lettres.
Moscow, Société Impériale des Naturalistes de Moscou.
... Société Impériale des Amis d'Histoire Naturelle, d'Anthropologie et d'Ethnographie.
Munich, Königlich-Bayerische Akademie der Wissenschaften (2 copies).
Naples, Zoological Station, Dr Anton Dohrn.
Neufchatel, Société des Sciences Naturelles.
Oberpfalz und Regensburg, Historischer Verein.
Palermo, Signor Agostino Todaro, Giardino Botanico.
Paris, Académie des Sciences de l'Institut.
... Société d'Agriculture.
... Société de Géographie, 184 Boulevard St Germain.
... Société Géologique de France.
... Société d'Encouragement pour l'Industrie Nationale.
... Dépôt de la Marine.
... Société Mathématique.
... École des Mines.
... Muséum d' Histoire Naturelle, Jardin des Plantes.
... L'Observatoire.
... École Normale Supérieure.
... École Polytechnique.
... Revue Scientifique, et Revue Littéraire et Scientifique (M. Alglave).
Prague, Königliche Sternwarte.
... Königlich-Böhmische Gesellschaft der Wissenschaften.
Rome, Accademia dei Lincei.
... Società degli Spettroscopisti Italiani.
Rotterdam, Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte.
St Petersburg, Académie Impériale des Sciences.
... Commission Impériale Archéologique.
... L'Observatoire Impérial de Pulkowa.
... Physikalisches Central - Observatorium.
Stockholm, Kongliga Svenska Vetenskaps-Academien.
Stuttgart, Verein fur Vaterländische Naturkunde zu Würtemberg.
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Upsala, Kongliga Vetenskaps-Societeten.
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Vienna, Kaiserliche Akademie der Wissenschaften.
... Novara Commission.
... Oesterreichische Gesellschaft für Meteorologie.

Vienna, Geologische Reichsanstalt.
... Zoologisch-Botanischer Verein.
Wellington, New Zealand Institute.
Zurich, University Library.

UNITED STATES OF AMERICA.

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Boston, the Bowditch Library.
... American Academy of Arts and Sciences.
... Society of Natural History.
Cambridge, Mass. U.S., Harvard University.
... Harvard College, Observatory.
New York, State Library.
Philadelphia, American Philosophical Society.
Philadelphia, Academy of Natural Sciences.
Washington, United States Coast Survey.
... United States Naval Observatory.
... United States Geological Survey of the Territories.
... The Smithsonian Institution.
Yale College, Newhaven, Connecticut.

SOUTH AMERICA.

Buenos Ayres, Public Museum, per Dr Burmeister.

(*All the Honorary and Ordinary Fellows of the Society are entitled to the Transactions and Proceedings. See notice at foot of next page.*)

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London, Geologists' University College Association.
... Mathematical Society, 22 Albemarle Street, London, W.
... Institution of Mechanical Engineers, Gower Street.
... Meteorological Office, 116 Victoria Street.
... The Meteorological Society, Westminster.
... Editor of the "Electrician," 396 Strand.
... Editor of "Nature," 29 Bedford Street, Strand.
Birmingham Philosophical Society.
Cornwall Geological Society.
Liverpool Literary and Philosophical Society.
Manchester Geological Society, 36 George Street.
Newcastle Philosophical Society.
Norfolk and Norwich Naturalists' Society.
Oxford Ashmolean Society.
Scarborough Philosophical Society.
Whitby Philosophical Society.

SCOTLAND.

Botanical Society of Edinburgh.
Geological Society of Edinburgh.
Scottish Meteorological Society.
Geological Society of Glasgow.
Philosophical Society of Glasgow.

COLONIES.

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... Philosophical Society.
Canada, Literary and Philosophical Society of Quebec.
Library of the Geological Survey, Canada.
Halifax, Nova Scotian Institute of Natural Science.
Hong Kong, China Branch of the Asiatic Society.
Madras Literary Society.
... Superintendent of Government Farms of Madras Presidency.
Melbourne, Royal Society of Victoria.
Shanghai, North China Branch of the Asiatic Society.
Sydney, Linnean Society of New South Wales.
... Philosophical Society of New South Wales.
Toronto, The Canadian Institute.

CONTINENT OF EUROPE.

Abbé Moigno, Rédacteur des "Mondes," Paris.
Bonn, Naturhistorischer Verein der Preussischen Rheinlande und Westfalens.
Bern, Naturforschende Gesellschaft.
Bordeaux, Société de la Géographie Commerciale.
Brunswick, Verein für Naturwissenschaft.
Cassel, Verein für Naturkunde.

Catania, Accademia Gioenia di Scienze Naturali.
Chemnitz, Naturwissenschaftliche Gesellschaft.
Cherbourg, Société Nationale des Sciences Naturelles.
Ghent, University Library.
Graz, Chemisches Institut der K. K. Universität.
Hamburg, Verein für Naturwissenschaftliche Unterhaltung.
Lausanne, Société Vaudoise des Sciences Naturelles.
Leipzig, Naturforschende Gesellschaft.
Lille, Société Géologique du Nord.
Milan, Società Crittogamologica Italiana.
Modena, Società dei Naturalisti.
Pisa, Nuovo Cimento.
Trieste, Società Adriatica di Scienze Naturali.
Tromsö, The Museum.
Utrecht, Provinciaal Genootschap van Kunsten en Wetenschappen.
Zurich, Naturforschende Gesellschaft.

UNITED STATES.

California, Academy of Sciences.
Cincinnati Observatory.
Cincinnati, Society of Natural History.
Connecticut, Academy of Arts and Sciences.
Davenport, Academy of Natural Sciences.
Massachusetts, Peabody Academy of Science.
Salem, The Essex Institute.
St Louis, Academy of Sciences.
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Fellows not resident in Edinburgh must apply for their Copies either personally, or by an authorised agent, at the Hall of the Society, within Five Years after publication.

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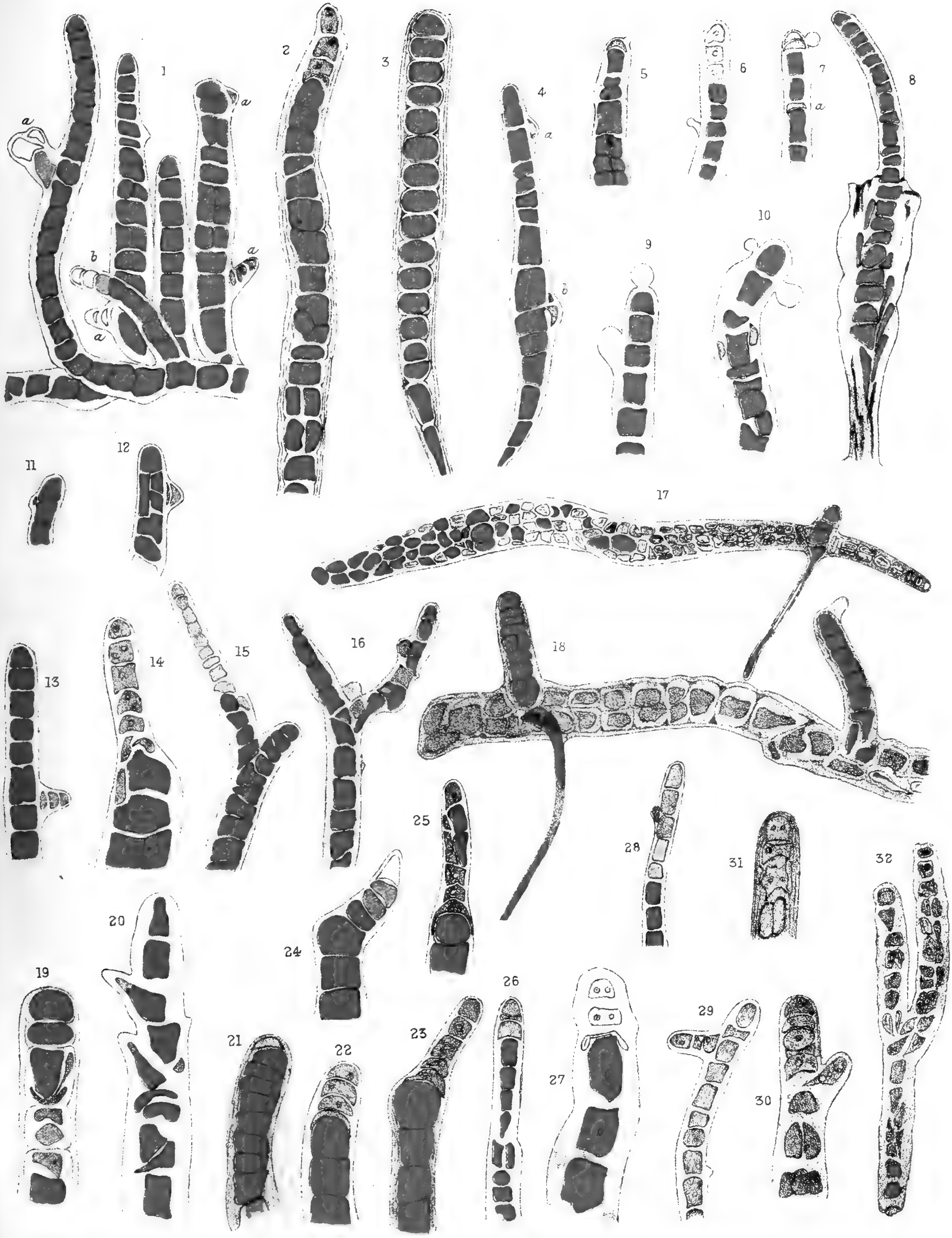
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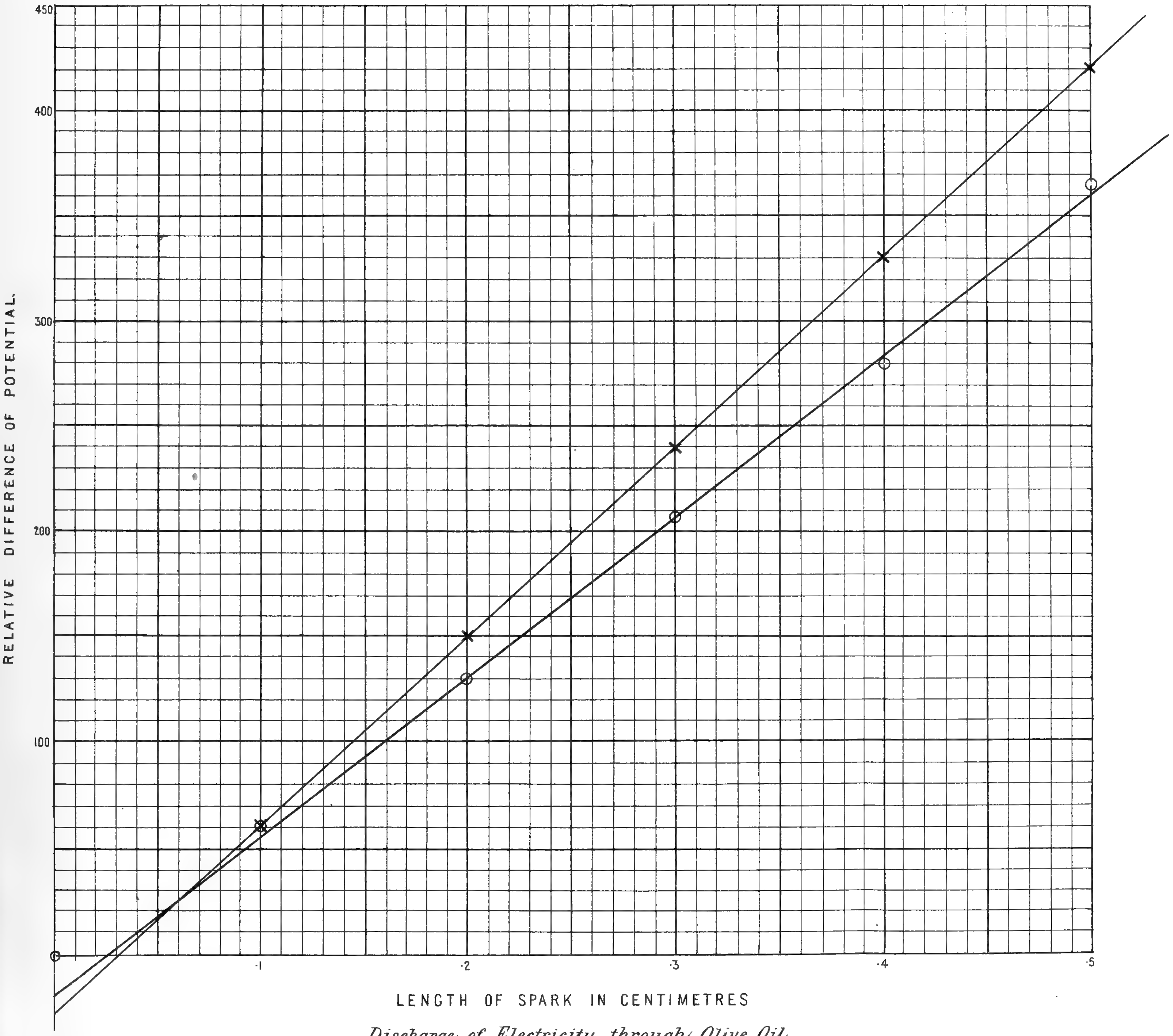

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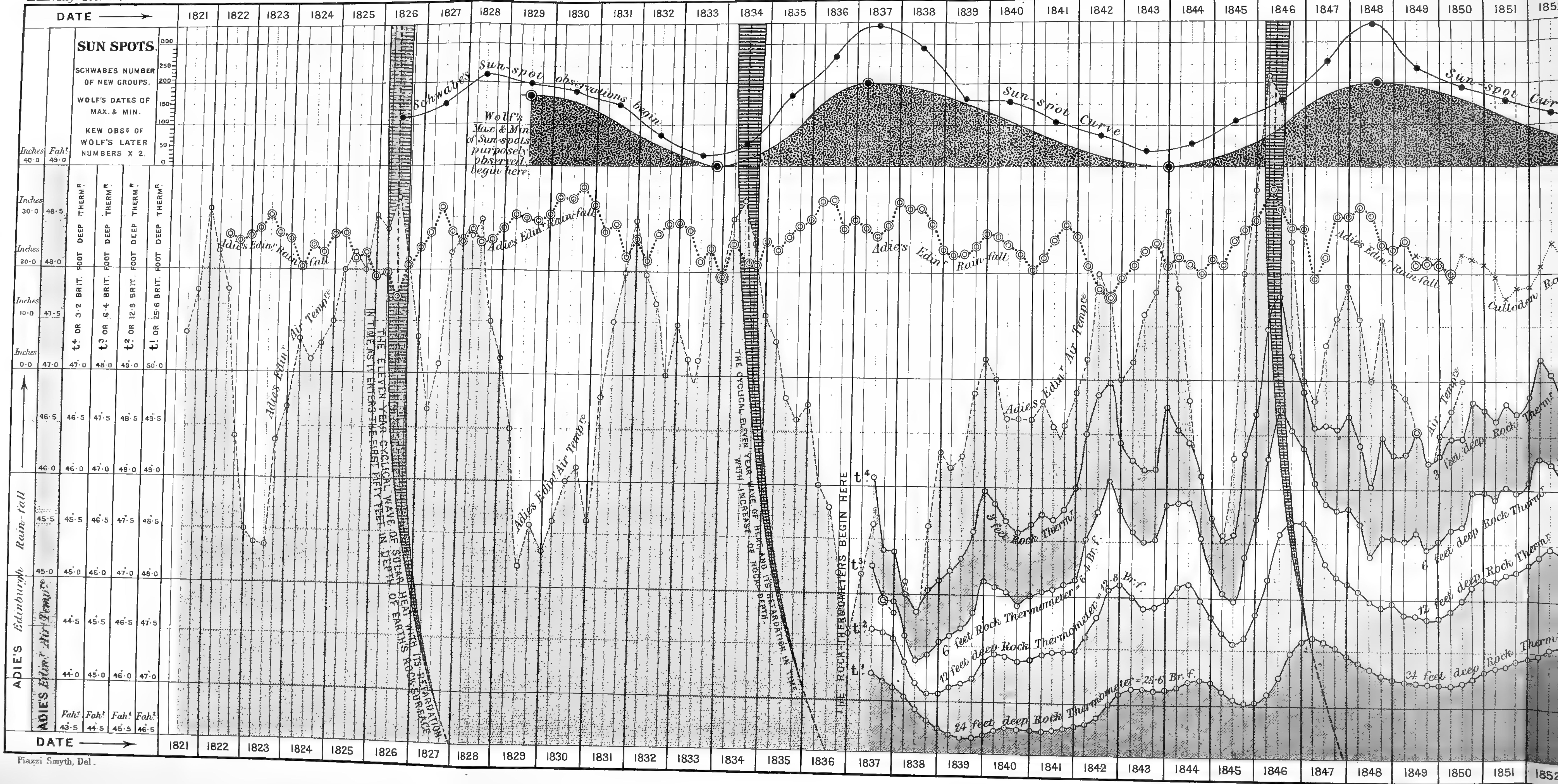

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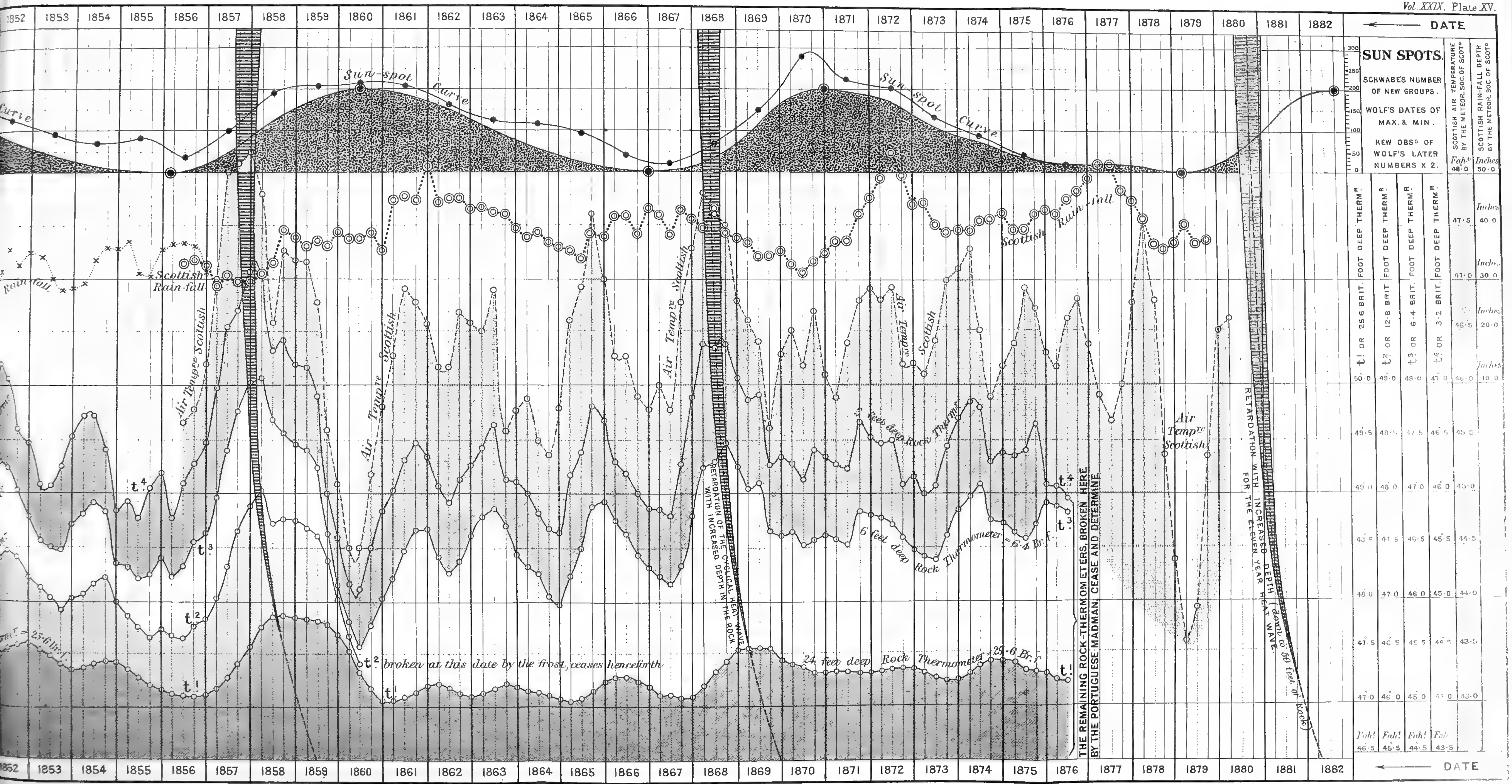

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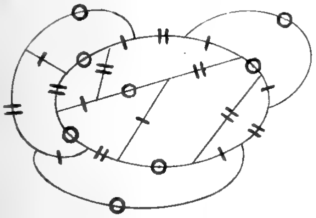

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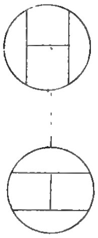

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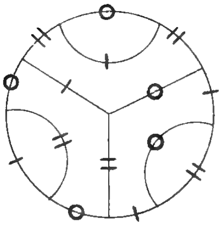

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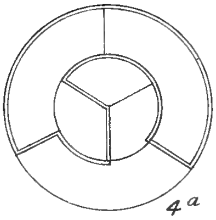

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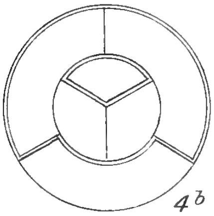

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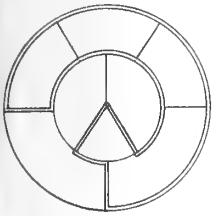

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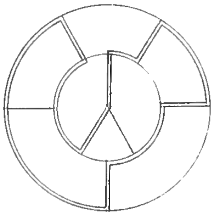

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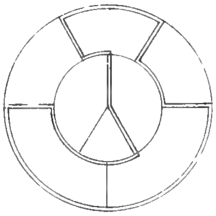

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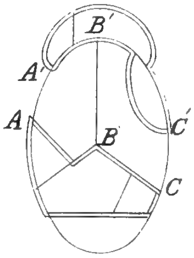

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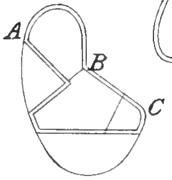

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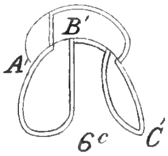

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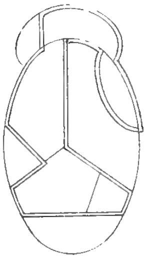

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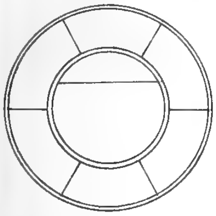

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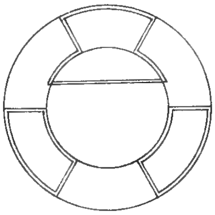

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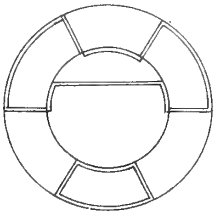

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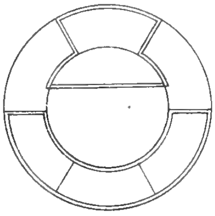

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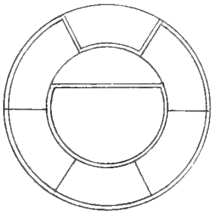

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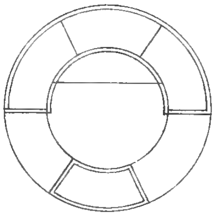

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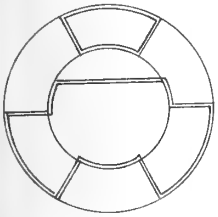

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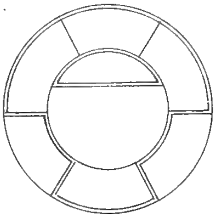

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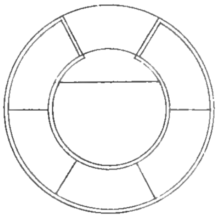

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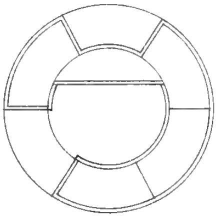

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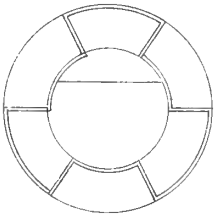

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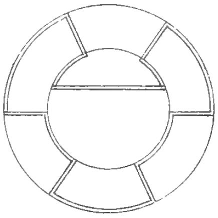

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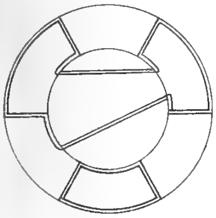

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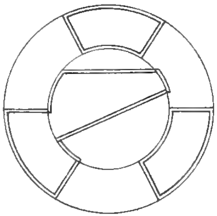

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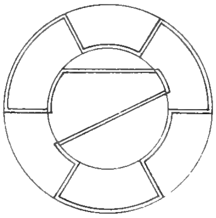

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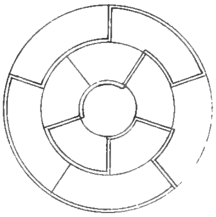

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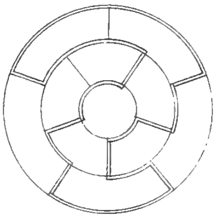

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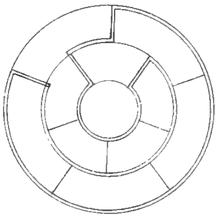

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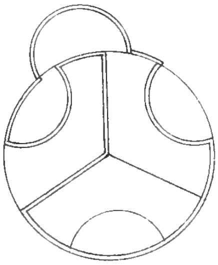

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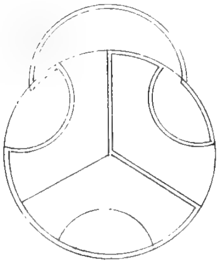

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J. Bartholomew Edin^r.

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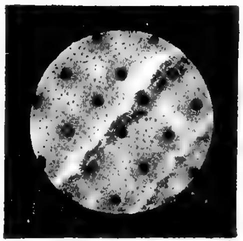

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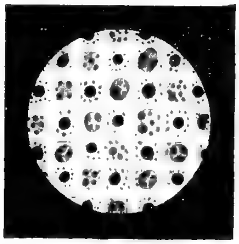

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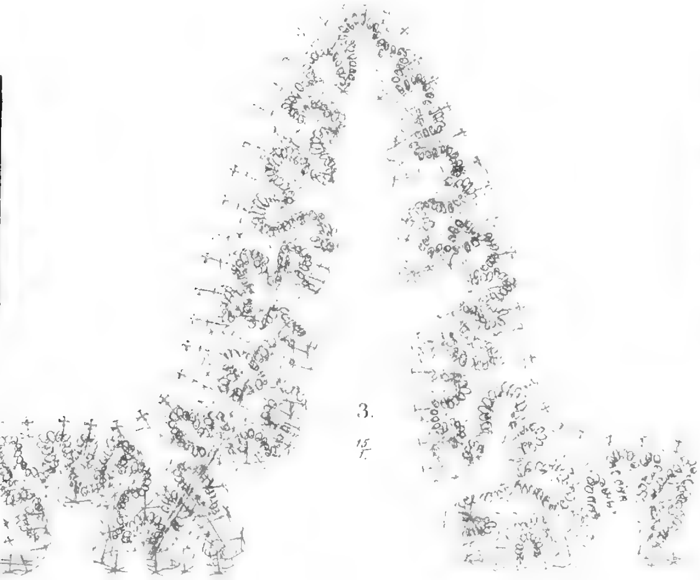

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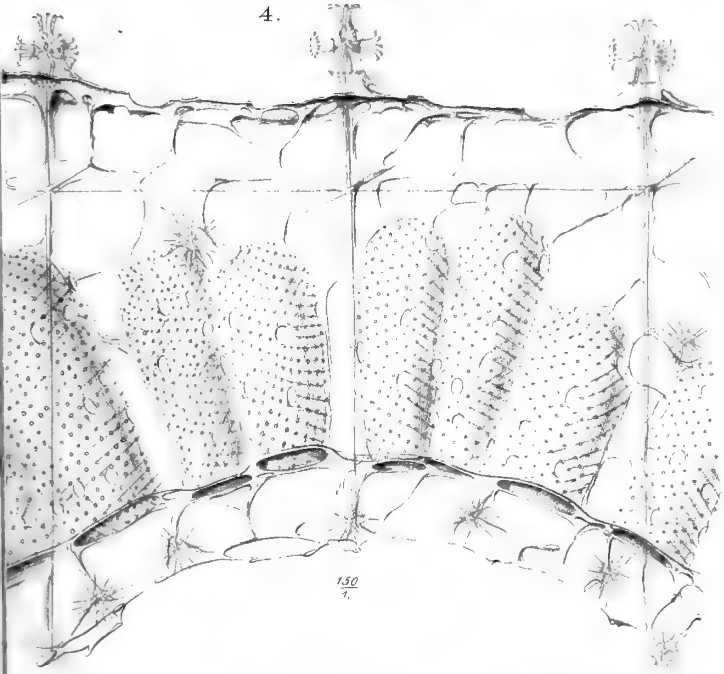

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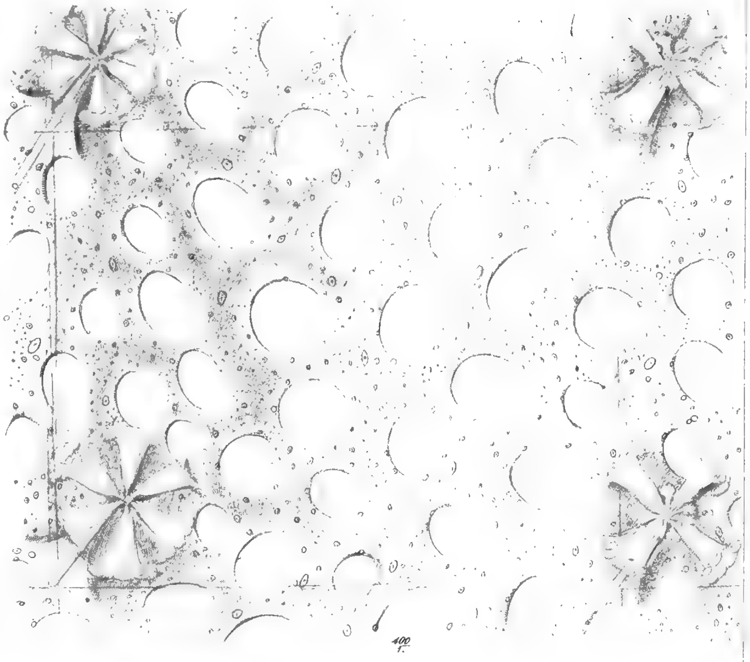
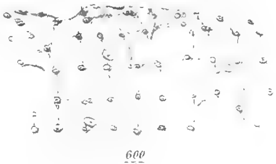


6.

7.



8.

Schulze del.

F. Huth, Lithr Edinr

EUPLECTELLA ASPERGILLUM. Owen.